Biobased Barrier: Exploring the Potential of Edible Coatings made from Bio-based materials to Extend the Shelf-Life of Tomatoes

Dissertation submitted to
Visvesvaraya National Institute of Technology, Nagpur
in partial fulfilment of the requirements for the award of
the degree

Master of Science

in

Chemistry

by

Aditi Sharma

(MS23CHM015)

under the guidance of

Prof. Anupama Kumar

Department of Chemistry
Visvesvaraya National Institute of Technology
Nagpur 440 010 (India)

May 2025

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Declaration

I, Aditi Sharma, hereby declare that this dissertation titled "**Biobased Barrier: Exploring the Potential of Edible Coatings made from Bio-based materials to Extend the Shelf-Life of Tomatoes**" is carried out by me in the Department of Chemistry of Visvesvaraya National Institute of Technology, Nagpur. The work is original and has not been submitted earlier, whole or in part, for the award of any degree/diploma at this or any other Institution / University.

Aditi Sharma
Date: 13/05/2025

Certificate

This to certify that the dissertation titled "**Biobased Barrier: Exploring the Potential of Edible Coatings made from Bio-based materials to Extend the Shelf-Life of Tomatoes**" is submitted by **Aditi Sharma** in partial fulfilment of the requirements for the award of the degree of **Master of Science in Chemistry,** VNIT Nagpur. The work is comprehensive, complete, and fit for final evaluation.

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Acknowledgement

This research work has been undertaken as a part of the final year M.Sc. Chemistry curriculum at Visvesvaraya National Institute of Technology (VNIT), Nagpur. The main aim of this project is to facilitate a unified methodology that also gives first-hand experience of our education. This journey has been both intellectually stimulating and personally rewarding.

I would like to express my deepest gratitude and heartfelt appreciation to **Prof. Anupama Kumar**, Professor, Department of Chemistry, VNIT Nagpur, for her unwavering support, insightful guidance, and constant encouragement throughout this project. Her meticulous supervision, profound knowledge, and constructive feedback were instrumental in shaping the direction and quality of this research work. Her dedication and vision have served as a great source of inspiration.

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I would like to thank the DST-FIST programme for providing Instrumentation facilities.

Lastly, thanks to all of my family and friends for your warm-hearted goodness.

Abstract:

Tomatoes represent a crucial segment of India's horticultural landscape, ranking among the top cultivated and widely consumed vegetables in domestic as well as export markets. Nutritionally, tomatoes are an excellent source of vitamin C, vitamin A, folate, minerals such as potassium and magnesium, dietary fibres, and potent antioxidant lycopene, which is linked to reduced risks of cardiovascular diseases. However, their high moisture content (94-95%) and soft texture make them highly perishable, leading to physical damage and significant post-harvest losses within 5-7 days. Therefore, extending their shelf life is essential for reducing food waste and ensuring food security. Simultaneously, rising environmental concerns and the use of chemical-based resources in food packaging have fuelled demand for sustainable alternatives. In this context, edible coatings have gained considerable attention as an innovative, biodegradable solution made up of food-grade biopolymers that addresses both preservation and environmental concerns. Therefore, the objective of this study is to explore the impact of coating formulated using Pectin, Gum Arabic, and Aloe Vera gel (1.75:0.25:0.5 w/v) in 100 mL of water. Further, Carboxymethyl Cellulose (CMC) was added (0.11, 0.22, 0.33 w/v) and optimised to reduce spoilage and maintain the quality of tomatoes. Edible coating was characterized for its density, viscosity, refractive index, total phenolic content, antioxidant capacity, wettability, and zeta potential. The tomatoes were divided into five groups and coated using the dipping technique and stored under real-time conditions. The physicochemical properties of coated and uncoated (control) tomatoes were assessed for their weight loss, decay percentage, pH, titratable acidity, ascorbic acid content, lycopene content, total soluble solids, and respiration studies, over 1^{st}, 7^{th}, 14^{th}, and 21^{st} days of storage. It was observed that all coatings effectively maintained quality attributes compared to uncoated tomatoes. However, coating of Pectin, Gum Arabic, and Aloe Vera gel with 0.22g of CMC exhibited the highest efficacy by minimizing the weight loss by 10% and decay rate by 33% compared to uncoated tomatoes with high retention of ascorbic acid content (4.67 mg/ 100g) than uncoated tomatoes (2.59 mg /100g), indicating better protection of nutritional quality during storage days. Consumer perception studies depicted good acceptability. Given their edible, biodegradable, and non-reactive nature, these coatings present a sustainable and practical solution for extending tomato shelf life and improving post-harvest management.

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List of Abbreviations:

CMC	Carboxymethyl cellulose
AVG	Aloe-vera gel
GA	Gum Arabic
TPC	Total phenolic content
TSS	Total soluble solids
TA	Titarable Acidity
ABTS	2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)
DNPH	2,4-Dinitrophenylhydrazine
FC reagent	Folin Ciocalteu reagent

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CHAPTER 1

INTRODUCTION

1.1 The Global Challenge:

There is a rapid increase in the production of fresh fruits and vegetables due to rising population demand, improved living standards, and increased awareness of their multi-nutritional value, including vitamins A and C, as well as many essential minerals that are essential to human beings.[1] However, they are very perishable due to their high moisture content and high nutritional value, leading to the development of undesirable characteristics like microbial spoilage and mechanical damage during handling and transportation. Therefore, there is a reduction in their edible quality due to biochemical changes. According to the Food and Agriculture Organization estimates, nearly 30–40% of fresh produce is lost before consumption, posing a serious challenge in front of world's food security and sustainability. This makes the development of efficient post-harvest preservation strategies a critical area of research.[2]

1.2 Postharvest Strategies to Extend the Shelf-Life of Fruit and Vegetables:

To effectively extend the shelf life of fresh produce, a combination of postharvest techniques—including physical, chemical, and gaseous methods—is often employed. These strategies are most effective when integrated with optimal storage temperature control.[1]

1.2.1 Physical Treatment:

a) Heat Treatment:

In recent years, heat treatment has gained attention as a promising alternative to chemical methods for preserving fresh fruits and vegetables after harvest. Techniques like hot water dipping, exposure to saturated water vapor, hot dry air treatments, and hot water rinsing with brushing have shown encouraging results.[1] These thermal treatments offer multiple benefits. Firstly, they can help reduce chilling injuries and slow down ripening by deactivating certain enzymes responsible for degradation. Secondly, they can effectively eliminate harmful insect infestations. Thirdly, they contribute to minimizing fungal infections. Depending on the crop and purpose, the duration of heat application can vary from short bursts (up to an hour) to extended treatments lasting several days. This method has been successfully used on a variety of produce: to maintain firmness in potatoes,

tomatoes, carrots, and strawberries; to retain vibrant colour in asparagus, broccoli, green beans, kiwi, celery, and lettuce; to prevent the development of off-flavours in melons like cantaloupe; and to extend the shelf life of grapes, plums, bean sprouts, peaches, and many more.

b) Irradiation:

Irradiation uses energy from gamma rays or electron beams to penetrate fresh produce and disrupt the DNA of pests and microbes, effectively preventing spoilage and extending shelf life. Sources like cobalt-60 or cesium-137 are commonly used for this purpose. The effect of irradiation depends on the dose: low doses (under 1 kGy) delay ripening and sprouting; medium doses (1–10 kGy) reduce microbial load, while high doses (above 10 kGy) can eliminate a wide range of pathogens but may harm the texture and flavour of fresh produce[1]. Typically, only low to medium doses are suitable for fruits and vegetables. Overall, irradiation offers a safe, effective, and non-chemical solution to improve food safety and shelf life. Beyond just preserving freshness and reducing spoilage, irradiation is also highly effective in eliminating or sterilizing insect pests that are a concern for quarantine. Contrary to common myths, irradiated food does not become radioactive. The process causes minimal chemical changes and has no negative impact on the food's nutritional value. Years of research confirm that irradiated foods are safe and wholesome for consumption.

c) Edible Coating:

Edible coatings are thin, protective layers applied to the surface of fresh produce, either to enhance the natural waxy cuticle or to replace it if it has been removed. These coatings help reduce moisture loss, slow down respiration and spoilage, and preserve texture, colour, and aroma by creating a semi-permeable barrier. They also shield produce from mechanical damage and can carry functional additives like antioxidants, antimicrobials, and flavour compounds to enhance quality and safety. Made from natural materials such as lipids, polysaccharides, or proteins—or a blend of both—edible coatings have become a key innovation in extending shelf life and maintaining the freshness of fruits and vegetables.[1]

1.2.2 Chemical Treatments

a) Antimicrobial and anti-browning agents:

In the past decade, increasing cases of foodborne illnesses have raised concerns among consumers, producers, and regulators regarding the microbial safety of fresh fruits and vegetables (FFV). Outbreaks have been associated with produce such as lettuce, sprouts, cucumbers, and cabbage. To address this issue, both chemical and natural antimicrobial agents are utilized. Chlorine-based disinfectants like sodium hypochlorite (NaClO) are favoured due to their strong oxidizing power and low cost; however, their effectiveness is dependent on concentration and may result in off-flavours or even harmful by-products. Furthermore, their ability to reduce microbial loads can sometimes be limited[1]. Physical aids such as brushing or surfactants can enhance their effectiveness by modifying the waxy surface of produce. Nevertheless, concerns regarding the formation of potentially carcinogenic chlorinated compounds are prompting regulatory reviews, particularly in the EU. In contrast, peroxyacetic acid (PAA) presents a powerful and safer alternative. It has demonstrated strong efficacy against pathogens like E. coli and L. monocytogenes on various fruits and vegetables. For instance, PAA treatment of fresh-cut carrots significantly reduced bacterial and fungal loads, with no regrowth during storage.

b) Nitric Oxide:

Nitric oxide (NO) is a reactive gas that plays a key role in fruit ripening and ageing plant processes. In fresh fruits and vegetables, natural NO levels drop as they mature, which opens the door for external NO application to slow down ripening and extend shelf life. When applied correctly, NO can delay the ripening phase in many tropical fruits by reducing ethylene production, a hormone closely linked to fruit ripening[1]. This is achieved either by fumigation or using NO-releasing compounds like sodium nitroprusside. NO works by forming stable complexes with enzymes involved in ethylene synthesis, effectively slowing down its production. It also interacts with other plant hormones, regulates gene activity, and helps reduce oxidative stress after harvest, making it a promising tool in postharvest preservation.

1.2.3 Gaseous Treatments

a) Ozone

Ozone has emerged as a powerful alternative to traditional sanitizers in fresh produce preservation. With a much higher oxidizing potential than chlorine, ozone works faster and is more effective, especially against tough bacterial spores and parasites[1]. At safe concentrations, it quickly disrupts microbial cell walls. Studies have shown that fruits treated with ozone (e.g., 2.5 ppm) not only retain more nutrients like ascorbic acid, lycopene, and β-carotene but also show better antioxidant activity and less weight loss. Ozone-treated papayas, for instance, scored higher in sweetness and taste, making ozone a promising, non-thermal, and safe method for extending shelf life. It can be used in cold storage, washing systems, or water sterilization.

b) Ethylene

Ethylene plays a dual role in fresh produce—it can be both helpful and harmful. On the positive side, applying ethylene can speed up ripening, enhance colour, and improve the quality of fruits like bananas, mangoes, kiwifruit, and tomatoes. However, excess or uncontrolled ethylene can shorten shelf life, cause softening, discoloration, and even increase decay in fresh fruits and vegetables. Managing ethylene is crucial to preserving the quality of both climacteric and non-climacteric produce after harvest. Common strategies include cold storage, blocking ethylene production or action, and limiting exposure by carefully regulating temperature and air composition. New ethylene detection technologies are also helping monitor and manage levels during storage and transport more precisely.[1]

c) Controlled atmosphere storage:

Controlled Atmosphere (CA) storage involves actively adjusting and maintaining specific levels of oxygen and carbon dioxide inside sealed storage chambers, along with optimal temperature control. Unlike Modified Atmosphere Packaging (MAP), which passively changes the atmosphere, CA storage offers precise control. Typically, oxygen levels are lowered while carbon dioxide is increased, depending on the fruit or vegetable being stored. These changes help slow down respiration, delay ripening, and influence key

metabolic activities—like ethylene production, pigment development, and flavour compound formation—thereby extending shelf life and maintaining quality.

d) Modified atmosphere packaging:

Modified Atmosphere Packaging (MAP) involves sealing whole or cut fresh produce in plastic films to control the internal gas environment. It can be passive, where oxygen and carbon dioxide levels adjust naturally based on the product's respiration and packaging properties, or active, where a specific gas mix is introduced before sealing. Both methods aim to create an ideal atmosphere that slows down respiration and ageing, helping extend shelf life[1]. Advanced active MAP systems now also include features to absorb or release gases like oxygen, ethylene, and CO_2, as well as moisture, antimicrobials, antioxidants, and even flavours, further enhancing product quality and safety.

1.3 Disadvantages of Different Post-harvest Strategies:[1]

Treatment	Disadvantages	Commercial application example
Heat treatment	Increased energy expenses and additional workforce requirements	potato, tomato, carrot, strawberry, asparagus.
Irradiation	The process demands high upfront investment, faces inconsistent regulatory standards across regions, and struggles with slow consumer adoption due to lingering fears about radiation exposure.	potato, onion, strawberry and mango
Antimicrobial and anti-browning agents	Hard-to-reach areas inside fresh produce where treatments can't easily penetrate	apple, strawberry, lettuce, melon, orange, tomato, grapes, and fresh-cut produce
NO	For nitric oxide (NO) to be used commercially, there's a need to develop an intelligent delivery system that can release it in a controlled manner.	apple, banana, kiwifruit, mango,

Ozone	It fails to enter through the natural openings, highlighting the need for further investigation.	apples, cherries, carrots, garlic, kiwi,
Modified atmosphere packaging	Condensation inside the package results in microbial growth and decay of produce	strawberry, banana, cherries, carrots, fresh-cut

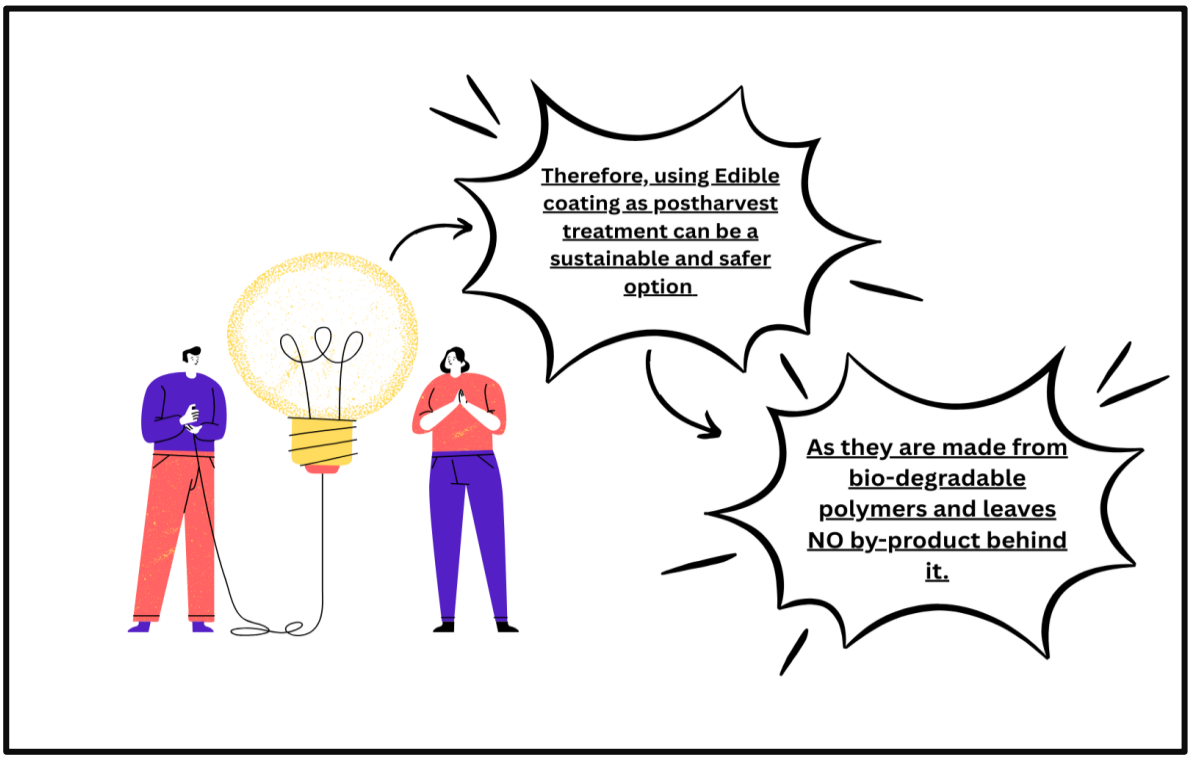
Therefore, using Edible coating as postharvest treatment can be a sustainable and safer option
As they are made from bio-degradable polymers and leaves NO by-product behind it.

Fig. 1.3 Edible coating as a sustainable and safer option

1.4 Edible Coating

1.4.1 Definition:

- When a layer of an edible material is applied on the surface of intact or minimally processed fruits and vegetables, forming a protective barrier, an edible coating is formed. This coating can preserve the quality of intact and minimally processed fruits and vegetables by acting as a barrier to gases, water vapour, and others.[3] The edible coating is a semi-permeable barrier aimed at extending shelf life by decreasing moisture and solute migration, gas exchange, oxidative reaction rates, and respiration, as well as physiological disorders on fresh-cut fruits.[4]

1.4.2 Possible components through edible coating can be made:[3]

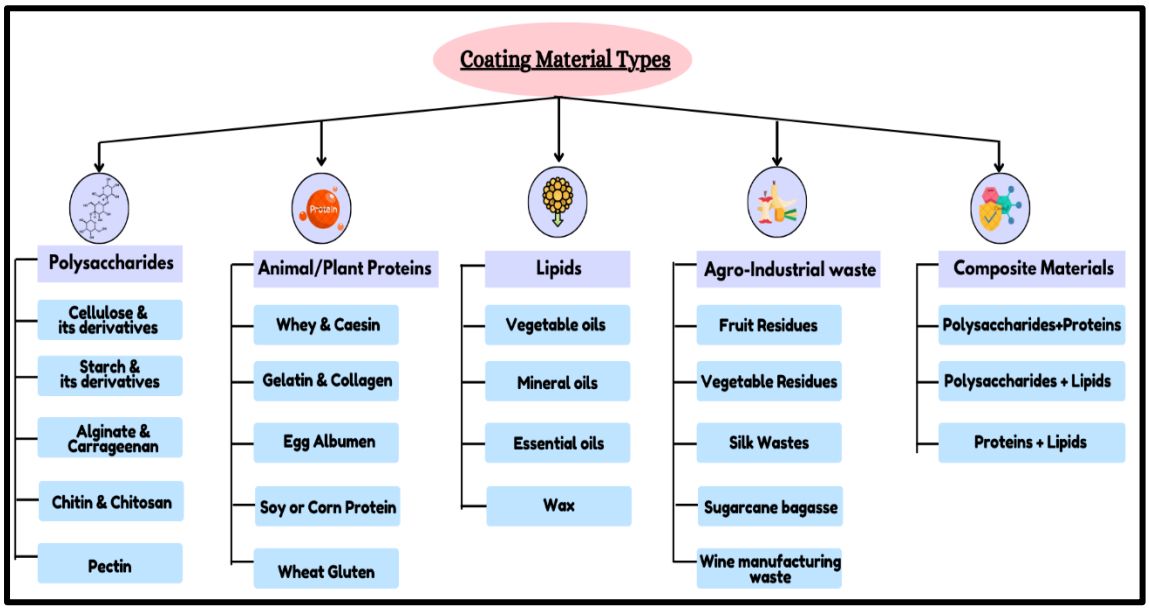

Fig. 1.4.2 Different components of edible coating

1.4.3 Benefits of Edible Coatings

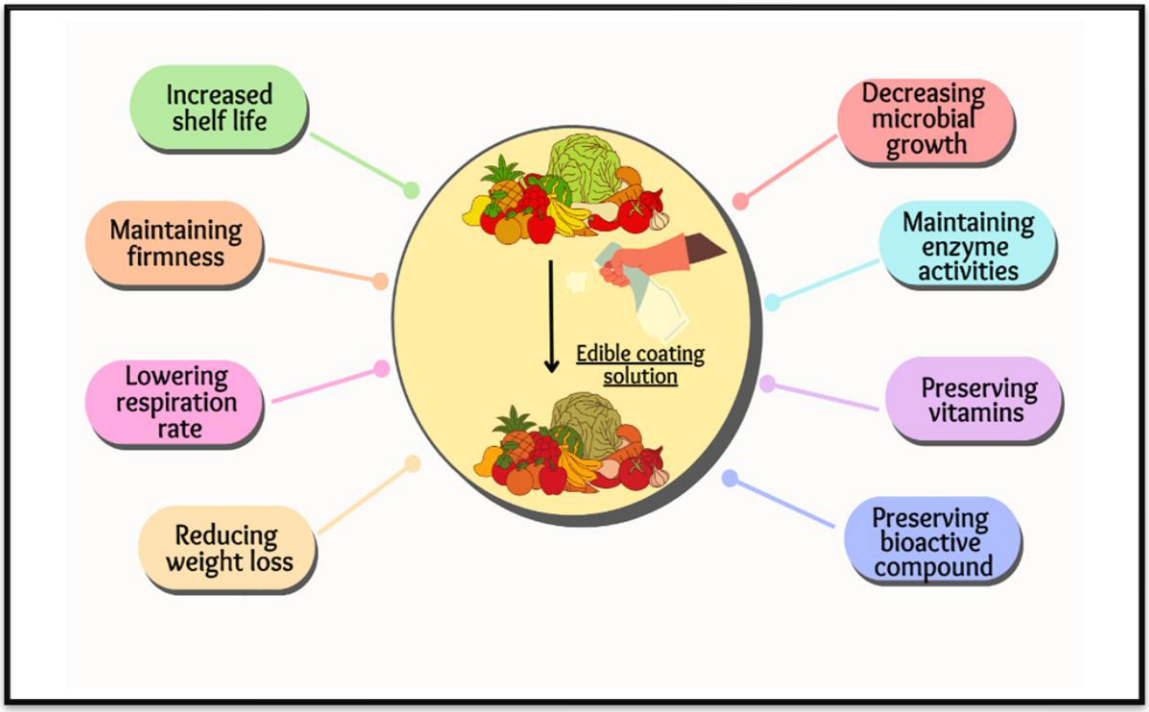

Fig. 1.4.3 Benefits in edible coating

a) Increased Shelf Life

Edible coatings act as protective barriers, reducing gas exchange and moisture loss. By slowing down respiration and metabolic processes, they extend the physiological life of produce. For example, pectin-based coatings significantly delayed senescence in mangoes and papayas by modulating internal atmosphere and slowing degradation processes.

b) Maintaining Firmness

Fruit and vegetable firmness is largely governed by the structural integrity of cell walls, like cellulose[5]. Edible coatings reduce enzymatic activity like polygalacturonase and cellulase, that degrade these components, thereby preserving texture.

c) Lowering Respiration Rate

Respiration is a major pathway for postharvest degradation, leading to energy loss and production of CO_2 and ethylene. Edible coatings limit oxygen ingress, reducing the metabolic rate. This slows down spoilage, especially in climacteric fruits like bananas and apples, where high respiration accelerates ripening and senescence.

d) Reducing Weight Loss

Weight loss in fresh produce is mainly due to water evaporation. Edible coatings act as moisture barriers, reducing transpiration and preserving freshness[3].

e) Decreasing Microbial Growth

Many edible coatings incorporate natural antimicrobials such as essential oils, organic acids, or silver nanoparticles. These inhibit microbial colonization on the surface, reducing decay[6].

f) Maintaining Enzyme Activities

Postharvest senescence is often accompanied by undesirable enzymatic reactions, such as peroxidase and lipoxygenase activity, which lead to off-flavours and browning. Coatings can modulate internal atmosphere to retain beneficial enzymatic functions (e.g., SOD and catalase) while suppressing degrading enzymes. This contributes to better biochemical stability.[6]

g) Preserving Vitamins

Water-soluble vitamins, especially vitamin C and B-complex, are highly sensitive to oxidation.[6] By limiting oxygen exposure and providing a physical barrier, edible coatings slow down oxidation and degradation of vitamins. Vitamin C retention is a key quality parameter in citrus fruits and tomatoes, where edible coatings have proven effective.

h) Preserving Bioactive Compounds

Polyphenols, flavonoids, and carotenoids—collectively known as bioactive compounds—have antioxidant properties but degrade rapidly postharvest. Coatings with antioxidant additives (e.g., ascorbic acid, essential oils) reduce oxidative stress and protect these compounds. Studies on coated bell peppers and papayas revealed significant preservation of carotenoids and flavonoids.[6]

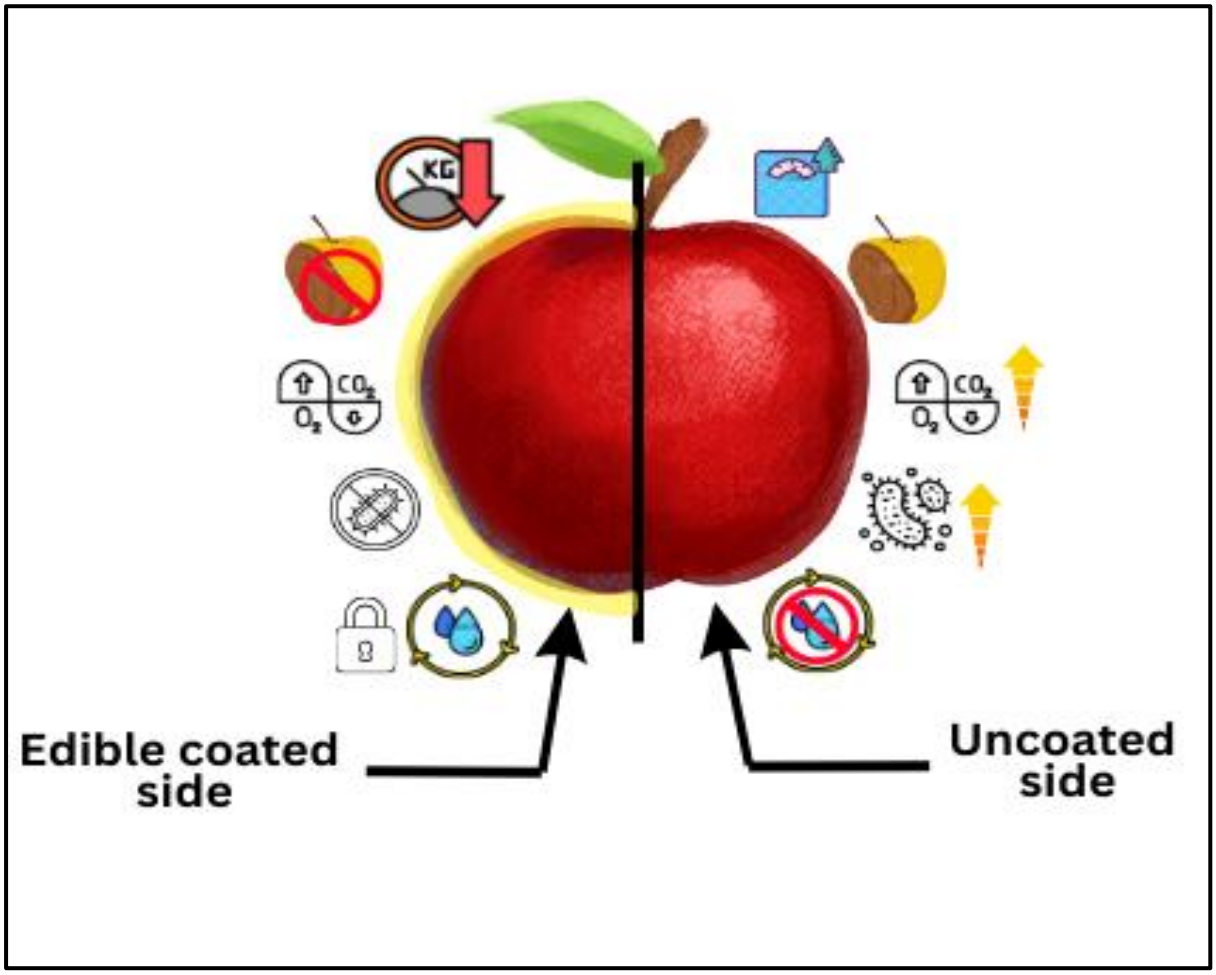

Fig.1.4.4 Difference in the coated and uncoated parts of the fruits

1.5 Bio-polymer selected for the Formulation of Edible Coating

1.5.1 Pectin

Pectin is a complex polysaccharide found in the cell walls of plants, commonly extracted from fruits like apples, citrus fruits, and berries. It consists of α-d-galacturonic acid units linked by (1→4) glycosidic bonds. Pectin is widely used in the food industry due to its various functional properties[7]. Pectin is a naturally occurring, water-soluble polysaccharide widely used for forming edible coatings. It is typically extracted from edible plant sources like citrus peels or apples using water-based methods. One of its standout features is its ability to form gels under specific conditions, which makes it especially valuable in food products such as jams, jellies, marmalades, and candies. Beyond its role in traditional foods, pectin is gaining popularity as a sustainable ingredient for edible coatings[8]. Notably, it can be obtained in significant amounts from agricultural waste, making it both eco-friendly and economically viable for large-scale use. Additionally, apart from its gelling properties, pectin acts as a dietary fibers and offers various health benefits. It can help regulate cholesterol levels, promote digestive health, and potentially aid in weight loss by providing a feeling of fullness[9].

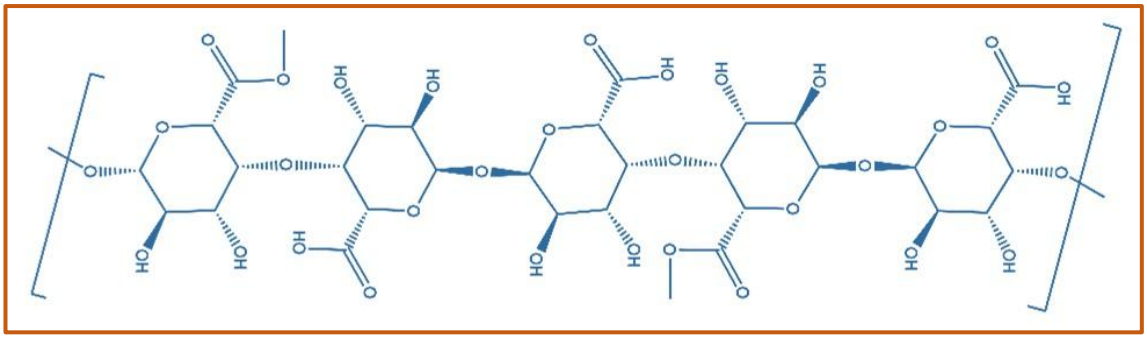

Fig 5.1.1 Structure of Pectin

1.5.2 Gum Arabic

In the development of edible coatings, natural polymers such as gum Arabic (GA) and cactus pear extract have emerged as particularly promising candidates. Their appeal lies in their widespread availability, affordability, and overall effectiveness in enhancing food preservation.[10] Gum Arabic, in particular, stands out as an environmentally friendly biopolymer derived from the exudates of Acacia tree branches and stems (Acacia spp.). Its chemical composition includes various monosaccharides—namely rhamnose, galactose, arabinose, and glucuronic acid—along with essential mineral ions such as calcium (Ca),

magnesium (Mg), and potassium (K). Despite its advantages, GA's high hydrophilicity can sometimes limit its water barrier properties, as it allows moisture to pass through more easily[11]. Nevertheless, it remains a highly valuable material in the food industry. Its functional characteristics—such as excellent film-forming ability, emulsification capacity, and potential for encapsulation—make it a safe and commercially accepted additive. These properties enable gum Arabic to be effectively used in various food applications, particularly as a base material in edible coatings designed to extend the shelf life and quality of fresh produce.[10]

1.5.3 Aloe Vera Gel

Aloe vera gel (AVG), owing to its hydrocolloidal nature, has emerged as a promising natural material for extending shelf life and preserving the postharvest quality of various perishable commodities[12]. Composed of approximately 99% gel, AVG serves as a rich reservoir of bioactive constituents, including polysaccharides, amino acids, organic acids, and an array of essential minerals such as zinc, calcium, copper, magnesium, manganese, and phosphorus[13]. Additionally, it encompasses vital enzymes, sterols, gibberellins, and both water- and fat-soluble vitamins, along with phenolic compounds. These components are not only nutritionally beneficial but also impart potent antimicrobial and anti-mutagenic effects[14]. AVG is widely acknowledged for its eco-friendly and non-toxic nature, making it a viable edible coating material. Its strong film-forming capacity, coupled with its biodegradability and antimicrobial action, enhances its role as a natural bio-preservative. Moreover, the presence of anthraquinones and related phenolics contributes significantly to its ability to inhibit microbial growth, positioning Aloe vera gel as a practical, affordable, and sustainable option for postharvest food preservation applications[15].

1.5.4 Carboxymethyl cellulose

Carboxymethyl cellulose (CMC), a cellulose-derived compound, is an anionic, linear polymer with a long-chain structure and high molecular weight[16]. It has gained attention as a natural, food-safe material for edible coatings due to its non-toxic, hypoallergenic, biodegradable, and organoleptically neutral (odourless and tasteless) properties. CMC-based films are transparent and flexible, offering good resistance to oils and fats. However, their water solubility and moderate permeability to moisture, oxygen, and carbon dioxide

must be considered when designing effective preservation systems.[17] Importantly, CMC coatings help slow down fruit ripening and deterioration by acting as antifungal and antisenescence barriers, thereby maintaining firmness and structural integrity. By regulating gas exchange between the fruit and its external environment, CMC films create a modified micro atmosphere around the produce, which supports extended freshness and controlled moisture and oxygen levels[18]. Furthermore, CMC is economically accessible and widely used across various fruit types such as apples, mandarins, fresh-cut mangoes, pears, sweet cherries, and papaya[19]. Its versatility is enhanced when used in combination with other preservation techniques, such as irradiation, in fruits like plums, peaches, and mangoes. As such, CMC stands out as a commercially viable and effective edible coating material for prolonging shelf life and preserving fruit quality postharvest.[17]

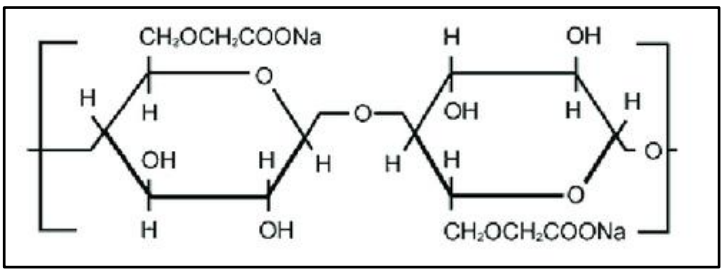

Fig.1.5.4 Structure of CMC

1.5.5 Glycerol

Glycerol—also known as glycerin or by its IUPAC name, propane-1,2,3-triol—has the chemical formula $C_3H_8O_3$. In the structure of triglycerides (the main constituents of fats and oils), glycerol acts as a backbone, with each of its three hydroxyl (-OH) groups bonded to a long fatty acid chain. Because it contains three hydroxyl groups, glycerol is classified as a polyhydric alcohol. At room temperature, glycerol is a clear, thick, colourless, and odourless liquid. One of its most notable features is its hygroscopic nature—it readily absorbs moisture from the air. This is made possible through hydrogen bonding, thanks to the presence of those -OH groups. Glycerol is highly soluble in polar solvents like water, methanol, ethanol, and phenol. Glycerol is widely used in edible coatings due to its multifunctional properties that enhance the performance and stability of the coating film. As a plasticizer, glycerol plays a key role in improving the flexibility and elasticity of coatings, especially those made from biopolymers like pectin, starch, chitosan, or gum

Arabic, which can otherwise be brittle[17]. By inserting itself between polymer chains, glycerol reduces intermolecular hydrogen bonding, making the film softer and less prone to cracking. Its hygroscopic nature allows it to absorb and retain moisture from the environment, which helps in maintaining the freshness and texture of food items by preventing surface drying. Additionally, glycerol can enhance the barrier properties of the coating against gases like oxygen, thereby delaying oxidation and microbial spoilage, which extends the shelf life of the coated product.[17]

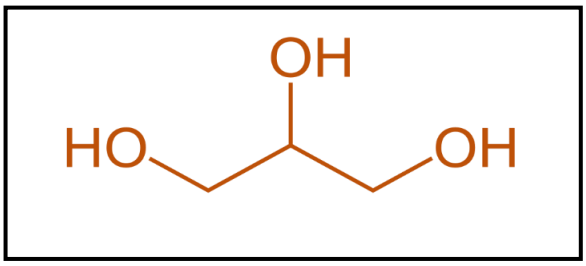

Fig 1.5.5 Structure of Glycerol

1.6 Edible coating on Tomatoes:

Tomato (*Solanum lycopersicum L.*) is the world's second-most grown horticultural crop after potato, belonging to the family *Solanaceae*, usually grown in tropical to temperate regions of the world. The worldwide popularity of tomato is due to its unique umami flavor, pleasant aroma, and inherent phytonutrients comprising phenolic compounds, vitamin C, lycopene, and β-carotenoids that are known to have health-promoting benefits. Epidemiological research has shown that intake of whole tomato or its processed products help in the management and reducing the risk of various chronic diseases like cardiovascular and prostate cancer due to the presence of lycopene, a carotenoid having excellent antioxidant properties.[20] Tomatoes are generally consumed as raw salad, as an ingredient in many cuisines, and processed into a plethora of products such as soups, ketchups, purees, and drinks. Tomatoes, being climacteric and highly perishable, have a naturally short post-harvest shelf life, typically ranging from 7 to 14 days under ambient conditions, depending on the variety and environmental factors. This limited longevity makes them particularly vulnerable to rapid physiological degradation and microbial spoilage. According to a report by the World Resources Institute (WRI) India, about 15% of tomatoes are wasted at the farm level, and an additional 12% is lost at the retail stage due to poor handling, storage, and inefficient distribution practices (Business Standard, 2024). Furthermore, studies estimate that total post-harvest losses of tomatoes in India can

reach up to 20–40%, depending on regional and infrastructural challenges (MDPI, 2023). These substantial losses not only result in economic hardships for farmers but also contribute to environmental degradation and food insecurity. Therefore, extending the shelf life of tomatoes through post-harvest interventions, such as the application of edible coatings, is a vital strategy to minimize spoilage, reduce food waste, and ensure that more produce successfully reaches consumers in a marketable condition[21].

1.7 Research Objective

This study aims to explore how an edible coating made from Pectin, Gum Arabic, and Aloe Vera gel, combined with different concentrations of Carboxymethyl Cellulose (CMC), can help extend the shelf life of tomatoes and reduce spoilage. Tomatoes, known for their high moisture content, are highly perishable and tend to spoil within just 5–7 days after harvest, leading to significant food waste. This research focuses on how biodegradable coatings can be a sustainable solution to slow down spoilage by reducing weight loss, decay, and maintaining the nutritional quality of tomatoes, particularly the levels of ascorbic acid and lycopene. By testing the coatings under real-time storage conditions, the study also aims to understand their effectiveness in preserving tomatoes, while addressing environmental concerns by offering an eco-friendly alternative to traditional chemical-based packaging. Additionally, consumer acceptance of these coated tomatoes is evaluated to ensure the practical viability of using such coatings in everyday food systems. Ultimately, this research seeks to link the reduction of spoilage with broader environmental and sustainability goals, offering a potential solution to both food waste and packaging waste.

1.8 Graphical Abstract

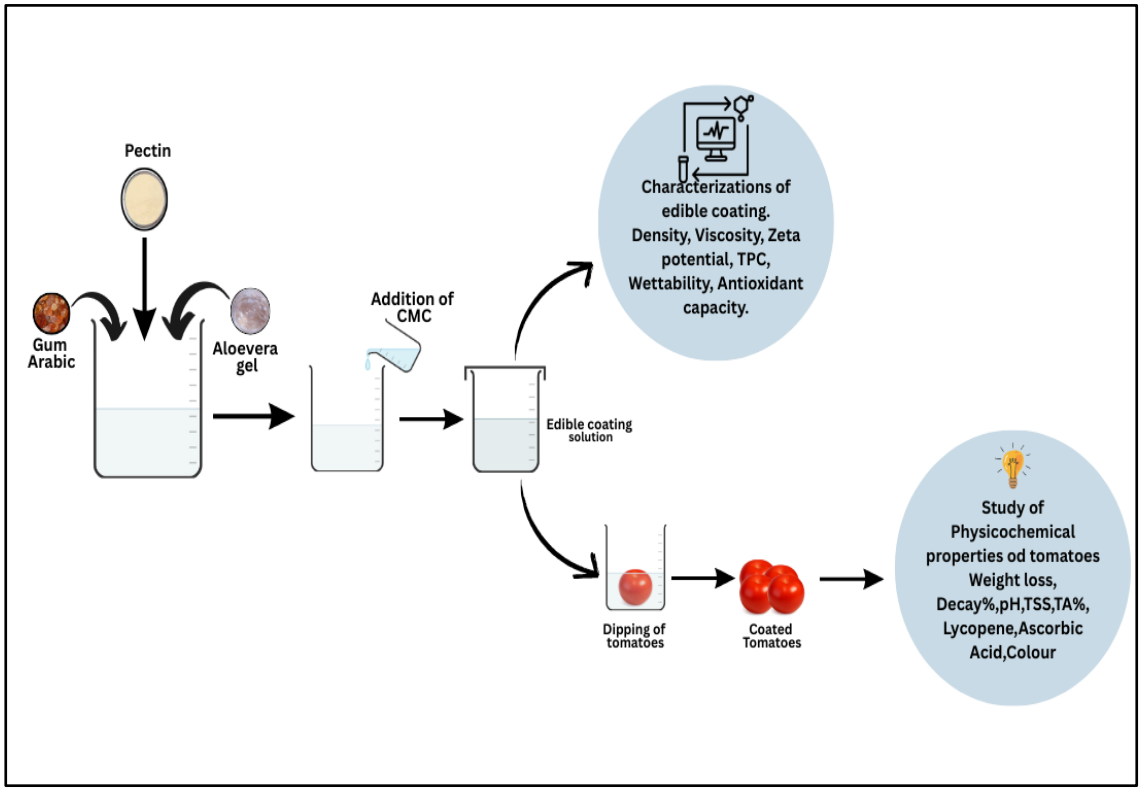
Pectin
Gum Arabic
Aloevera gel
Addition of CMC
Edible coating solution
Characterizations of edible coating. Density, Viscosity, Zeta potential, TPC, Wettability, Antioxidant capacity.
Dipping of tomatoes
Coated Tomatoes
Study of Physicochemical properties od tomatoes Weight loss, Decay%,pH,TSS,TA%, Lycopene,Ascorbic Acid,Colour

Fig.1.8 Graphical abstract

CHAPTER 2

LITERATURE SURVEY

Biopolymers	**Fruits and Vegetables used**	**Result**	**References**
Pectin-based edible coating.	Mango	Limited the transpiration and diminished weight reduction by water evaporation, also reduced respiration rate and prevented or delayed responses to ethylene	DOI: 10.1111/j.1745-4530.2010.00609.x
Gum Arabic-Based Edible Coating	Guava	Reduced weight loss, decay, and delayed fruit softening during cold storage.	https://doi.org/10.3390/coatings12010090
carboxymethyl cellulose- and pectin-based edible coatings	Strawberry	Inhibit the microbial decay, enzymatic, or biochemical damage	https://doi.org/10.1016/j.tifs.2021.02.025
pea starch and gum Arabic on	Oranges	The lower levels of respiration rates.	https://doi.org/10.1016/j.postharvbio.2017.11.003
Coating based on whey protein isolate, xanthan gum and clove oil	Tomato	Inhibit the microbial decay, enzymatic, or biochemical damage	https://doi.org/10.1016/j.meafoo.2021.100005
Guar Gum as an Edible Coating	Tomato	Reduced weight loss, decay, and delayed fruit softening during optimal conditions	https://doi.org/10.1155/2017/8608304
Aloe vera Gel-Based Edible Coating	Fresh-cut papaya	provided an oxygen barrier and reduced respiratory rate, increasing the firmness retention and keeping a high C^* value.	https://doi.org/10.1155/2020/8303140
Carboxymethyl Cellulose from Banana Rachis base edible coating	Strawbe-rry	inhibiting biochemical or microbiological decays in fruits, as well as physical or textural degeneration; thus, avoiding unfavourable responses such as microbial growth and softening	https://doi.org/10.3390/agriculture13051058

Carboxymethyl cellulose and cardamom oil in a nanoemulsion edible coating	Tomato	Reduced both oxidative damage and bacterial growth	https://doi.org/10.1016/j.bcab.2022.102369
Pectin-Based Edible Coating Combined with Chemical Dips Containing Antimicrobials and Anti browning Agents	Pear	The formulation of the chemical dip following pectin coating contributed to the protection of the phenolic content and to the enhancement of the antioxidant activity of fresh-cut pears during storage.	https://doi.org/10.3390/horticulturae8050449

Table 2.1 Literature survey

CHAPTER 3

MATERIALS AND METHADOLOGY

This section describes the materials used during the study. All the chemicals, solvents, and reagents used in this project were purchased from authentic chemical vendors with high-purity standards. In addition to this, it is ensured that all other ingredients utilized in this study were of analytical grade. The Pectin Powder was purchased from the Urban Platter. The Gum Arabic was purchased from Forest Found, the Aloe vera gel was purchased from Tejaswini Enterprises, and Carboxymethyl Cellulose was purchased from Bakerville Purix, whereas Glycerol Anhydrous was from the Emparta ACS.

Freshly harvested tomatoes *(Solanum lycopersicum)* samples of the variety Sahoo, developed by Syngenta, the Saaho (TO-3251) is a determinate hybrid, were obtained from the commercial supplier in Nagpur, India. Fresh tomatoes of equal size, disease-free, with blemishes, and of uniform color for the experiment. All materials, including surfaces and utensils in contact with tomatoes were previously sanitized.

3.1 Formulation of Edible Coating Solutions

The Pectin powder used in the formulation was (7% w/v), it was used to provide the matrix of the coating, the Gum Arabic was (1% w/v) used to provide the stability to the coating, the aloe vera gel was (2% w/v) used to enhance the texture of the coating as well to provide the antimicrobial activity. The edible coating formulation was optimized with the help of Carboxymethyl Cellulose (CMC) in different concentrations of it, the CMC provides the antibacterial property to the formulation. The Glycerol was (2%w/v) added as a cross-linking agent. The following table provides the weight ratio of the different components of edible coating formulation. Pectin and Gum Arabic were dissolved in cold water under continuous stirring, followed by the addition of aloe vera gel. Simultaneously, CMC was dissolved in hot water, cooled to room temperature, and then added to the mixture with continuous stirring. Finally, glycerol was incorporated to obtain the edible coating solution.

Table 3.1 All components in (w/v) in 100 ml of water

Name	Pectin	AVG	Gum	CMC	Glycerol
AG	7	2	1	0	2
AG.11	7	2	1	1	2
AG.22	7	2	1	2	2
AG.33	7	2	1	3	2

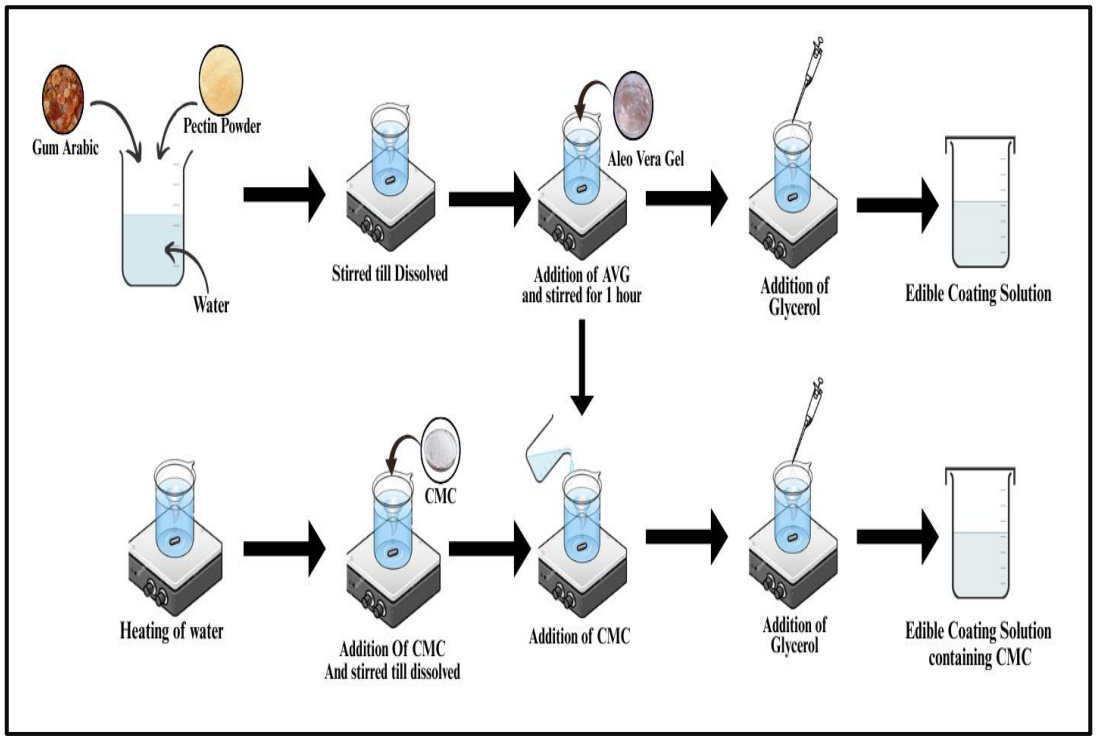

Fig 3.1 Preparation of edible coating

3.2 Characterization of edible coating

The characterization of edible coatings is a crucial step in evaluating their suitability and effectiveness in food preservation. It provides detailed insights into the coating materials' physical, mechanical, chemical, and functional properties.[22]

a) Density & Viscosity :-

Parameters such as density and viscosity are critical for understanding the flow behaviour & application properties of the coating solution, as they directly influence film formation, uniformity, and adherence to the food surface[22]. Density is measured with the help of the Anton Paar Portable Density Meter. Viscosity is measured with the help of the Anton Paar Viscometer, ViscoQC 300R Rotational.

b) **pH**

pH plays a crucial role in determining the chemical stability and potential oxidative deterioration of the coating during storage and its compatibility with the food matrix. pH is measured with the help of the Mettler Toledo pH Meter.

c) **Refractive Index**

The refractive index (RI) of an edible coating is a valuable physicochemical parameter that provides insights into the formulation's optical properties, compositional consistency, and structural integrity. A key application of RI measurement is in evaluating the transparency and visual appeal of the coating, as consumer perception is often influenced by the appearance of coated food products.[22] It was measured with the help of the Digital Abbe Refractometer DR198 B

d) **Total Phenolic Content**

Total Phenolic Content (TPC) reflects the concentration of phenolic compounds in an edible coating, typically measured using the Folin-Ciocalteu method. While it doesn't specify individual phenolics or their activity, a higher TPC generally indicates greater antioxidant potential. This can help reduce lipid oxidation, browning, and nutrient loss in perishable foods. TPC measurement also supports formulation optimization when using plant-based ingredients for natural food preservation.[23]

e) **Total Antioxidant Capacity by ABTS Assay**

The ABTS assay is a widely used method to evaluate the antioxidant capacity of edible coatings by measuring their ability to neutralize ABTS•+ free radicals. A higher antioxidant activity, indicated by greater color fading, reflects the coating's potential to reduce oxidative stress, thereby preventing spoilage like lipid rancidity, discoloration, and nutrient loss[23]. This is especially valuable for coatings enriched with natural extracts, as the assay directly measures functional bioactivity rather than just the presence of phenolics.

f) **Surface Tension**

Surface tension is essential in edible coatings because it affects how well the coating spreads and sticks to the fruit's surface. If the tension is too high, the coating won't spread evenly, leading to poor coverage and reduced protection. A well-balanced surface tension allows for smooth, uniform coating that helps reduce moisture loss and spoilage. This ensures better preservation and shelf life for perishable produce like tomatoes.

g) **Wettability**

Wettability is a crucial property of edible coatings, as it determines the coating's ability to uniformly spread and adhere to the surface of food products. Good wettability ensures even coverage, which is essential for forming a consistent protective barrier that enhances shelf life and quality. It also influences how well bioactive components, such as antioxidants or antimicrobials, interact with the food surface. Poor wettability can lead to patchy films, reduced functional performance, and compromised visual appeal[24,25].

h) **Zeta Potential**

Zeta potential is an important indicator of the stability of edible coating formulations. It reflects the surface charge of particles in the coating solution, which directly affects how well the particles repel each other and remain evenly dispersed. A higher absolute zeta potential value (either positive or negative) suggests better stability, reducing the chances of particle clumping or settling over time[26]. This is crucial because a stable coating ensures uniform application on the fruit surface, which is necessary for effective moisture barrier properties and spoilage prevention.

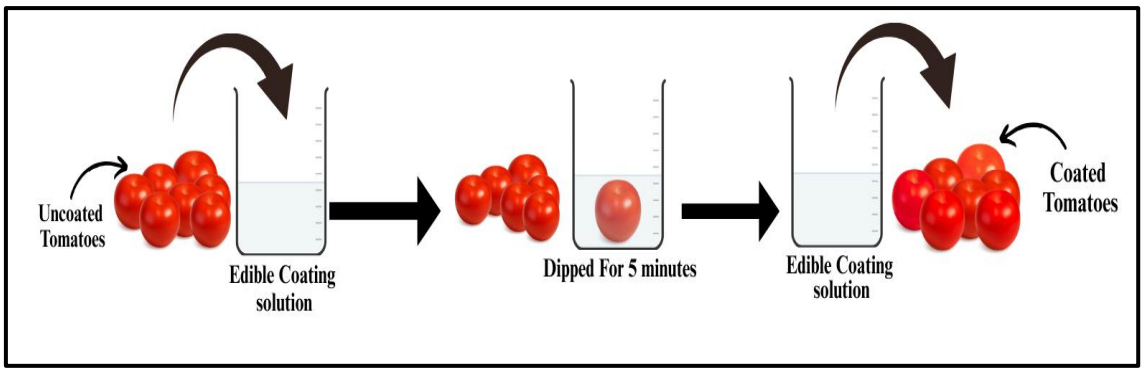

Fig. 3.3 Dipping of tomatoes in edible coating

3.3 Application of Coatings on Tomatoes

The purchased tomatoes were gently washed with tap water to detach any dust residues and soil. They were then dried at room temperature. The tomatoes were coated with edible material using the Dipping method[27]. The tomatoes were carefully immersed in an edible coating solution for approximately 5 minutes to ensure uniform coverage of the surface. After the dipping process, the tomatoes were removed from the solution and placed on clean trays under controlled conditions to allow the coating to dry and form a thin, consistent layer. Tomatoes were divided into five groups: Control (Uncoated tomatoes), AG, AG.11, AG.22, and AG.33 as presented in Table 1.

3.4 Physicochemical Properties of the Tomatoes

Understanding how tomatoes behave when coated with edible films is important because it helps us see whether these coatings truly help keep the fruit fresh for longer. Tomatoes, being soft and full of water, spoil easily and lose their texture, taste, and nutritional value during storage. By tracking changes in their key qualities—like acidity, sweetness, vitamin C, and firmness—we can judge how well the coating is working. These observations tell us not just if the coating slows down spoilage, but also if it protects what makes tomatoes healthy and enjoyable to eat. This kind of research also supports the shift toward safer, eco-friendly methods of food preservation, reducing the need for synthetic packaging or chemicals.

The study was conducted over a period of 21 days using tomatoes of the Sahoo variety, which were sourced from local vegetable vendors in Nagpur. The tomatoes were stored

under real-time conditions with relative humidity ranging between 53% and 58%, and ambient room temperatures fluctuating between 24°C and 27°C. The study of the properties was done on the 1st,7th,14th, and 21st days of storage.

a) Weight loss%

Tomatoes from each treatment group were initially weighed, followed by additional measurements on the 1st, 7th, 14th, and 21st days of the experiment using a digital balance. Weight loss for each fruit was determined by subtracting the final weight from the initial weight and then dividing by the starting weight. The total weight loss was expressed as a percentage.[27]

$$Weight\ loss\ \% = \frac{loss\ in\ weight\ on\ that\ day\ of\ tomatoes}{initial\ weight\ of\ tomatoes} \times 100$$

b) Decay%

To evaluate the effectiveness of the edible coatings during post-harvest storage, the decay percentage of both coated and uncoated tomato samples was measured.[27] This was calculated by dividing the number of visibly decayed fruits by the total number of fruits recorded on the initial day of storage, and then multiplying the result by 100. This assessment helped determine the extent to which the coatings were able to inhibit microbial spoilage and maintain the visual and structural integrity of the tomatoes over time.

$$Decay\ \% = \frac{No.of\ tomato\ decayed}{Total\ number\ of\ tomatoes} \times 100$$

c) pH

Monitoring pH during storage evaluates the effectiveness of edible coatings in preserving freshness and preventing fermentation or spoilage, making it a vital parameter in post-harvest quality assessment. The pH of the tomato juice was evaluated with the help of the glass electrode pH meter.[10]

d) %Titrable acidity (TA)

Titratable acidity was determined by titrating the samples with 0.1 N sodium hydroxide, and the values were expressed as a percentage of citric acid. An acid factor of 0.0064 was used for citric acid calculations[27].

$$\text{Titrable acidity } (\%) = \frac{\text{Titre} \times \text{N of alkali} \times \text{Equivalent weight of acid} \times 100}{\text{Volume of sample} \times 1000}$$

e) Total soluble solids (TSS)

Total Soluble Solids (TSS) represent the concentration of dissolved substances in tomato juice, primarily sugars, acids, and other soluble nutrients that contribute to the fruit's flavour and nutritional quality. The instrument was calibrated with distilled water before use to ensure accurate readings[27]. Monitoring changes in TSS during storage helps assess the impact of edible coatings on the preservation of internal fruit quality over time. It is measured with the help of a handheld refractometer (ºBrix).

f) Ascorbic acid

The ascorbic acid content of tomato samples was determined using a UV-Visible spectrophotometer. Initially, 5 grams of tomato were finely chopped and homogenized in 50 mL of 10% acetic acid solution. After allowing the mixture to settle, 2 mL of the clear extract was carefully pipetted out. To this, 0.1 mL of bromine water and 0.1 mL of thiourea were added, followed by 2 mL of DNPH (2,4-dinitrophenylhydrazine) reagent. The resulting mixture was then incubated for 3 hours to allow complete reaction. Finally, the absorbance was measured at 540 nm using 10% acetic acid as the reference blank. This method allowed for the quantitative analysis of ascorbic acid content in the tomato samples during storage.[10]

g) Lycopene content

Lycopene content was quantified using a UV-Visible spectrophotometer. For the analysis, 1 mL of tomato juice was mixed with 19 mL of a solvent mixture prepared in a 2:1:1 ratio of hexane, acetone, and ethanol. To this, 5 mL of ice-cold distilled water was added to facilitate phase separation[10]. The mixture was then covered with aluminium foil to protect it from light exposure, since lycopene is light-sensitive, and stored under refrigeration for optimal extraction. After the phases settled, the absorbance of the upper hexane layer was

measured at 503 nm using hexane as the blank reference. This method enabled the accurate determination of lycopene concentration in the tomato samples.

h) Respiration rate

Tomato ripening is marked by a sharp increase in respiration rate, accompanied by a rise in O_2 uptake and CO_2 production, known as the climacteric peak. This surge drives the metabolic processes responsible for ripening. As the fruit matures, the respiration rate gradually declines, along with reduced gas exchange. By acting as semi-permeable barriers, edible coatings help regulate O_2 and CO_2 diffusion, thereby lowering the respiration rate. This control delays ripening, preserves quality, and extends the postharvest life of tomatoes. The respiration rate was measured with the help of O_2/CO_2 gas analyser.

i) Colour

Colour is a key indicator of ripeness, quality, and consumer acceptability in tomatoes. It reflects underlying biochemical changes, such as chlorophyll degradation and the accumulation of lycopene and β-carotene during ripening. Measuring colour parameters (L*, a*, b*) provides objective data on the ripening stage, helping to assess the effectiveness of treatments like edible coatings in delaying or modifying ripening. Colour data also correlates with other physicochemical properties such as pH, total soluble solids, and antioxidant activity, offering a non-destructive, visual proxy for internal changes. In this study, colour measurement supports the evaluation of coating performance by indicating whether ripening was slowed compared to uncoated controls. The colour was measured with the help of a handheld Hunter Lab colorimeter.

3.5 Sensory Evaluation

Sensory evaluation is essential for assessing the consumer acceptability of tomatoes based on appearance, texture, aroma, and flavour. It complements physicochemical tests by revealing how quality changes are perceived. A favourable sensory profile indicates that edible coatings effectively preserve desirable traits, enhancing both shelf life and market appeal.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Characterization of Edible Coating

The comprehensive physicochemical characterization of the developed edible coating formulation is essential to evaluate its performance, stability, and overall suitability for application on fresh produce. This section focuses on analyzing the data obtained from various experimental techniques used to assess the formulation's core properties. The parameters investigated include density, viscosity, pH, total phenolic content (TPC), wettability, surface tension, and zeta potential.

In the following sections, each of these parameters is discussed in detail, supported by the data obtained through experimentation. The results are interpreted in the context of their functional significance, helping to establish a strong scientific basis for the efficacy and potential of the coating in real-world applications. By examining these interrelated physicochemical traits, a comprehensive understanding of the coating system is developed, offering valuable insight into how the formulation can be optimized for postharvest use.

4.1.1 Density:

Table 4.1.1

Coating solution	Density (g/cm^3)
AG	1.004±0.0003
AG.11	1.005±0.0005
AG.22	1.0076±0.0004
AG.33	1.009±0.0005

The table below displays the density (g/cm^3 at 25ºC) of the edible coating solution composed of Pectin, Gum Arabic, and Aloe vera gel with increasing concentration of CMC (Carboxymethyl cellulose). The base of the Edible coating solution remains constant in Pectin (1.75g), Gum Arabic (0.25g), and Aloe vera gel (0.5g) in 100 mL of water, while the CMC concentration is systematically increased. The density of the base formulation AG (without CMC) was found to be 1.004±0.0003g/cm^3. Upon the addition of CMC at 0.11g,0.22g, and 0.33g, the density progressively increased to 1.005±0.0005, 1.0076±0.0004, and 1.009±0.0005 g/cm^3, respectively. This trend is attributed to the synergistic interaction between CMC and the existing biopolymer, resulting in a tighter,

more cohesive polymer matrix. Increased hydrogen bonding, which binds water within a structure, increases the formulation's mass per unit volume. Such densification enhances the barrier and mechanical properties essential for effective edible coatings.

4.1.2 Viscosity:

Figure 4.1.2 below shows a dramatic increase in viscosity as the concentration of the CMC rises, culminating in a sharp transition at AG.33, indicating a gel-like behaviour.

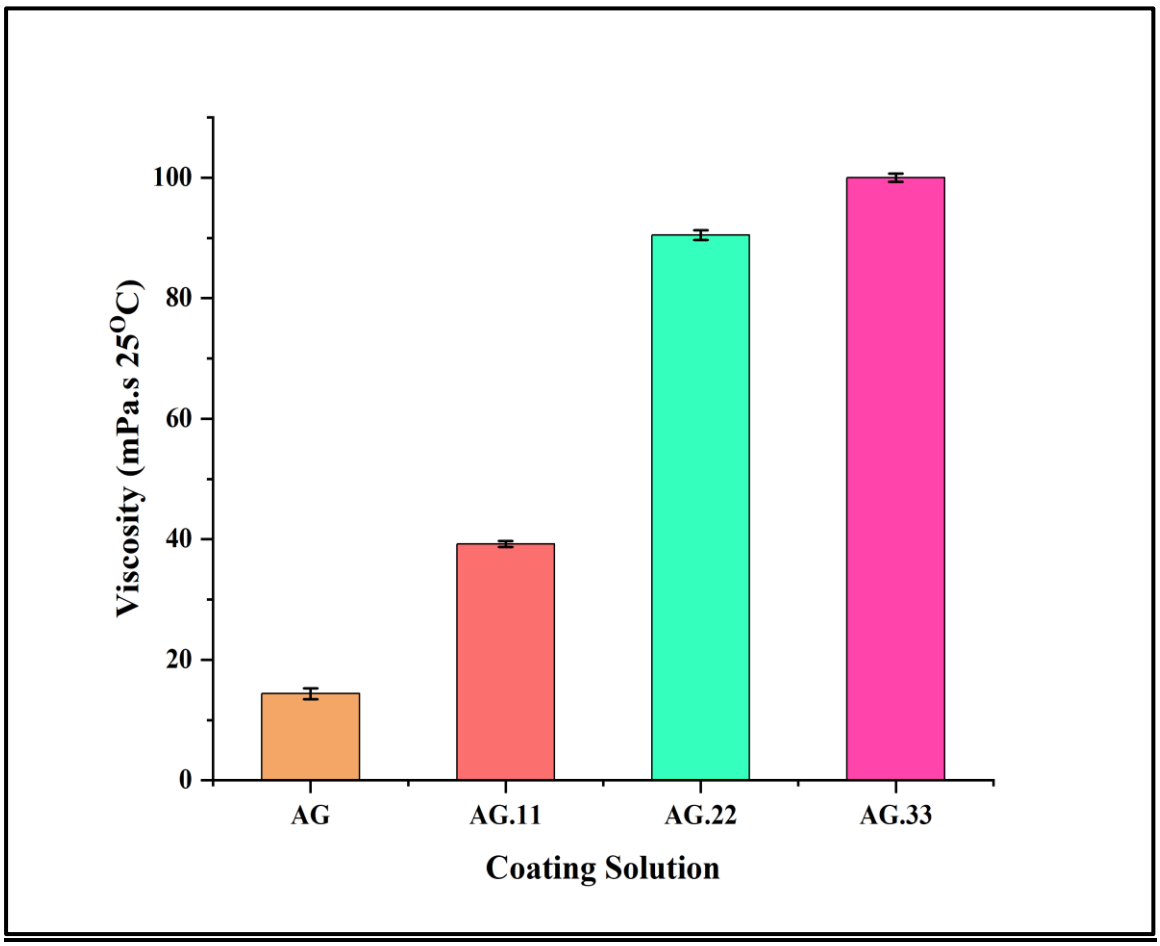

Fig 4.1.2: Viscosity of the edible coating with the increase in concentration of CMC

The base formulation that is AG exhibited a viscosity of 14.38±0.5 mPa.s. Upon increasing CMC to 0.11g and 0.22g, viscosity rose sharply to 39.24±0.4 mPa.s(AG.11) and 90.49±0.5 mPa.s(AG.22), respectively. At 0.33g of CMC (AG.33), the solution shifted from a viscous liquid to a gel-like consistency. The viscosity crosses from millipascal seconds (mPa.s) to pascal-seconds (Pa.s). This rise is attributed to an increase in polymer entanglement, water immobilization, and the formation of a semi-continuous 3D polymer network.

4.1.3 pH:

The above fig. 4.1.3 shows the pH of the different coating solutions. The graph reveals a clear upward trend in the pH from 2.91 to 3.58 as the CMC concentration increases. The base formulation AG displayed the lowest pH, 2.91±0.3, due to the natural acidity of pectin, gum Arabic, and aloe vera gel.

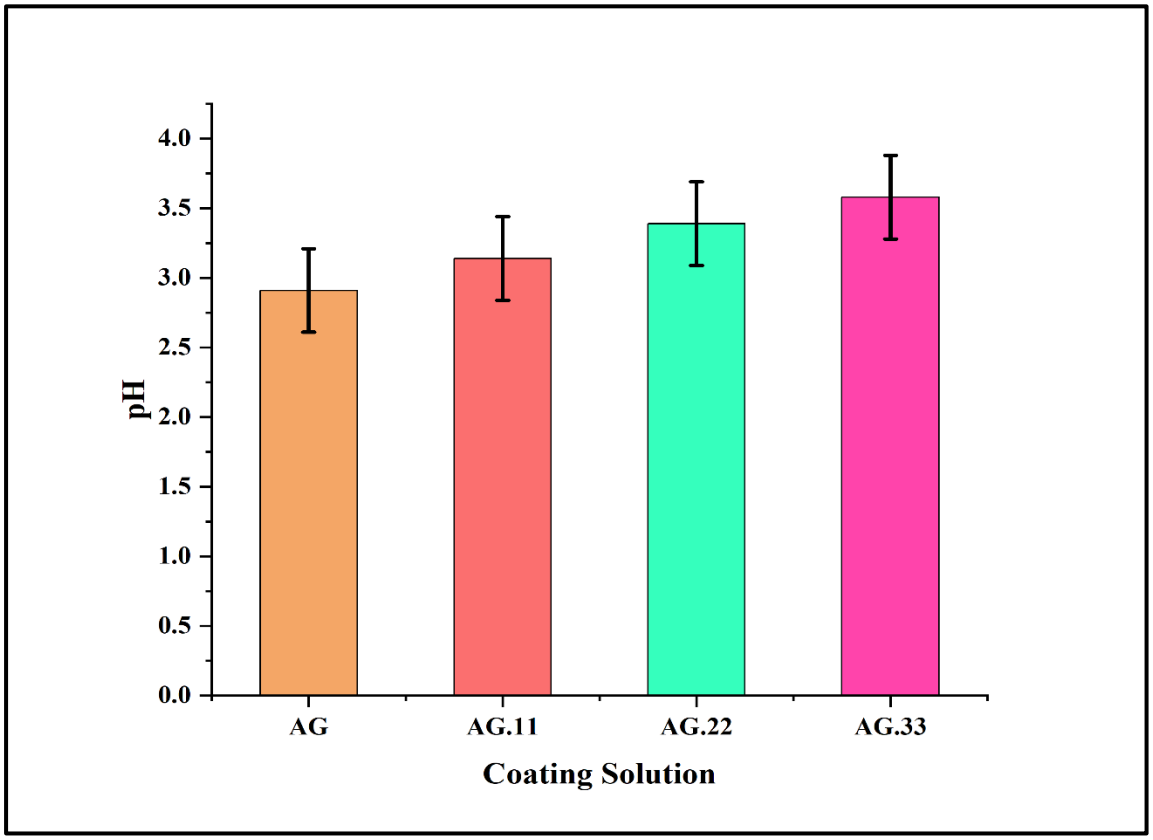

Fig 4.1.3: pH of the edible coating with the increase in concentration of CMC

The base formulation AG displayed the lowest pH, 2.91±0.3, due to the natural acidity of pectin, gum Arabic, and aloe vera gel. As the CMC concentration increased, the pH also progressively increased to 3.14±0.2, 3.39±0.3, and 3.58±0.5 in AG.11, AG.22, and AG.33, respectively. This rise is explained by the interaction of CMC with acidic functional groups, which reduces the number of free hydrogen ions in the solution. Additionally, at higher CMC concentrations, the polymer network becomes more saturated, decreasing the ionization of acid groups and mildly buffering the solution. This pH shifts are important as they influence microbial stability, and the electrostatic behaviour of the coating solutions.

4.1.4 Surface Tension:

The graph below shows the Surface tension of the edible coating solutions exhibiting a non-linear trend with increasing concentration of CMC.

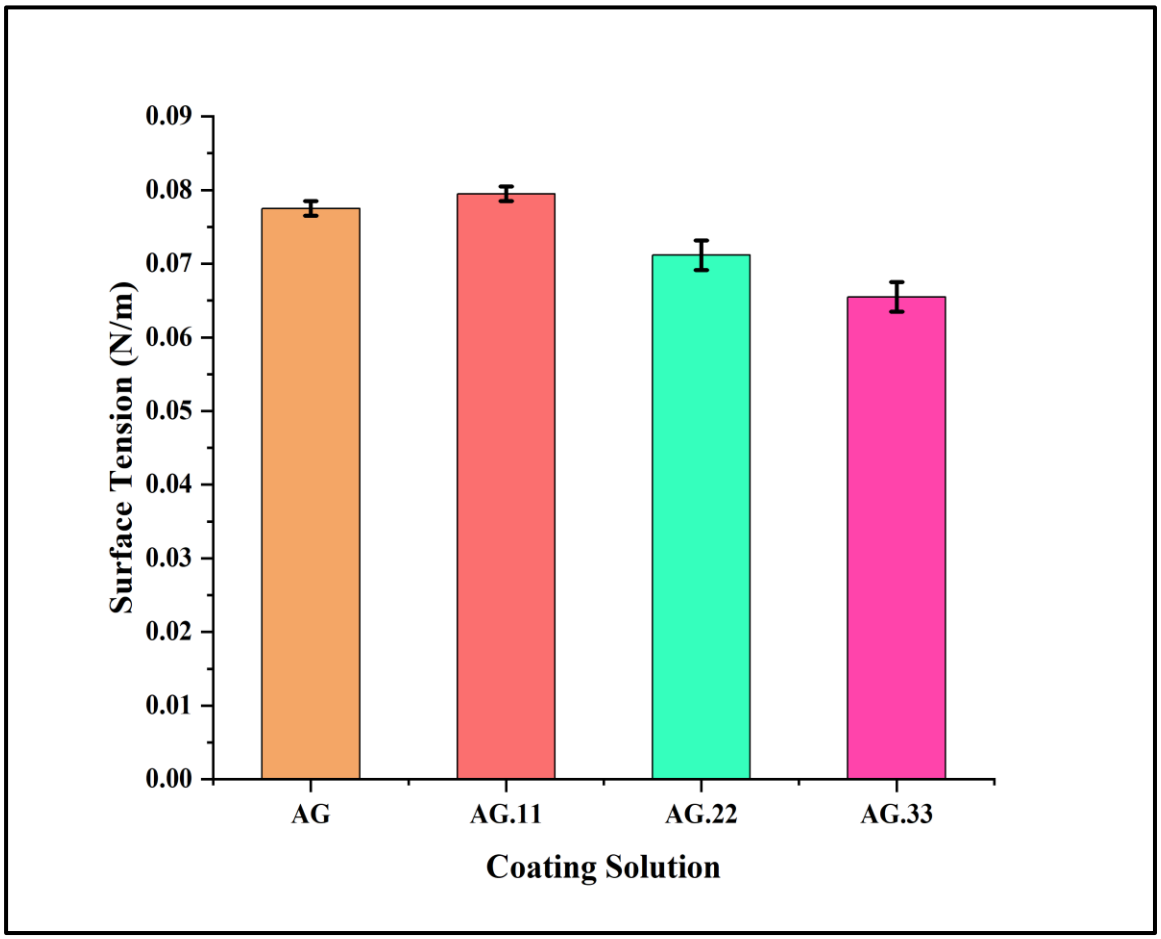

Fig 4.1.4: Surface tension of the edible coating with the increase in concentration of CMC

The AG has a surface tension of 0.00775±0.001 N/m. Upon the addition of 0.11g of CMC, which is AG.11 has a surface tension of 0.0795±0.001 N/m, which was increased slightly, likely due to cohesion between molecules at the interface. However, with a further increase in the CMC to 0.22g and 0.33G, AG.22 and AG.33, respectively, the surface tension was also decreased to 0.007116±0.002 N/m and 0.0065±0.002 N/m, respectively. This decline was attributed to the surfactant-like behaviour of CMC at higher concentrations, where it accumulates at the air-liquid interface and disrupts hydrogen bonding, thereby lowering cohesion forces. Reduced surface tension is beneficial for improving coating wettability, and adherence on the food surfaces.

4.1.5 Wettability:

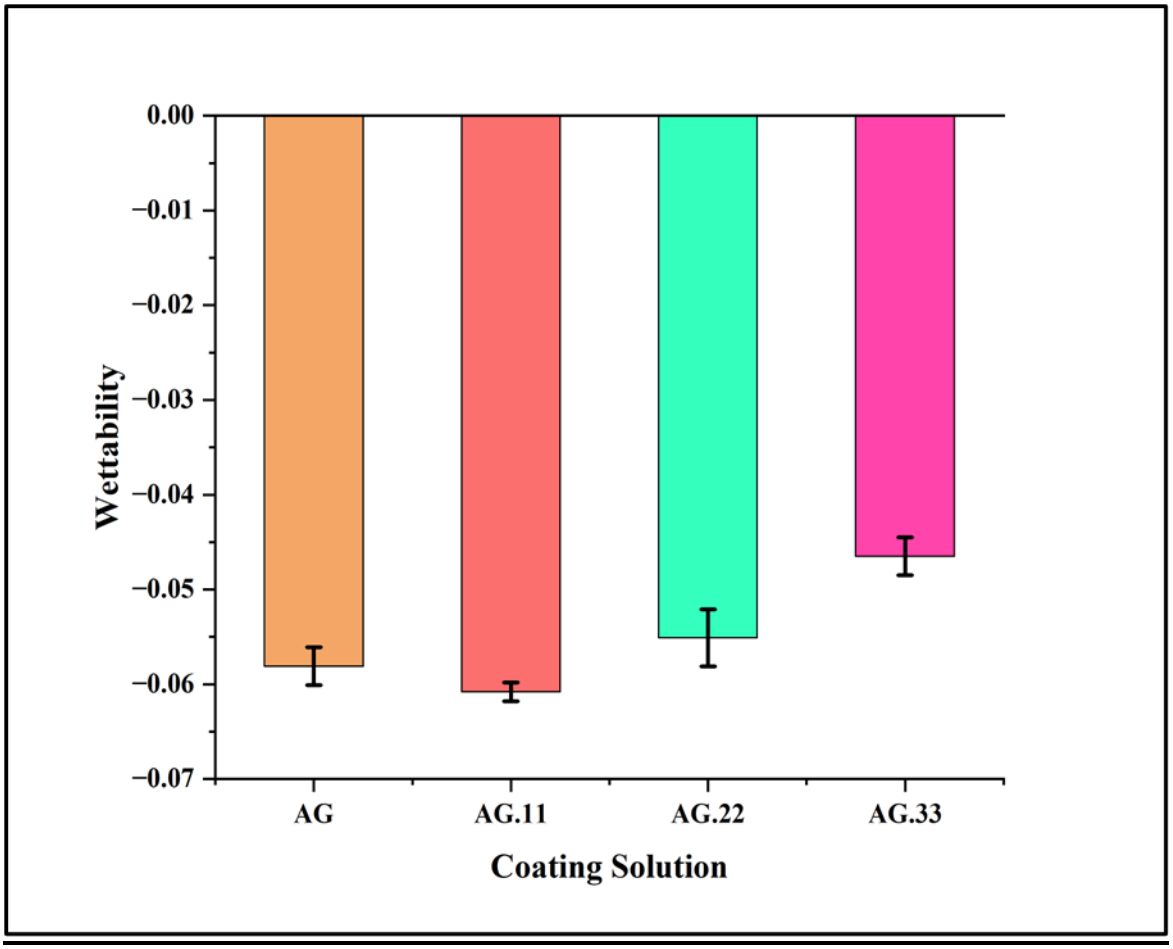

Fig 4.1.5: Wettability of the edible coating with the increase in concentration of CMC

The above graphs depict the wettability of the edible coating solutions. Wettability was evaluated using the spreading coefficient (Ws), where values closer to zero indicate better surface spreading and adhesion. The base formulation (AG) showed a Ws of -0.0581 ± 0.002, indicating good wettability. Upon incorporating CMC, the Ws values for AG.11, AG.22, and AG.33 were -0.0608 ± 0.001, -0.0551 ± 0.003, and -0.0465 ± 0.002, respectively. Overall, all four formulations showed Ws values near zero, confirming their favourable wettability and potential applicability as edible coatings.

4.1.6 Refractive Index:

As illustrated in the graph, the base formulation (AG), composed of pectin (1.75 g), gum Arabic (0.25 g), and aloe vera gel (0.5 g), exhibited an RI of 1.3360±0.005.With the addition of CMC at increasing concentrations, the RI values rose progressively, with

AG.11, AG.22, and AG.33 displaying RI values of 1.3368±0.002, 1.3376±0.001, and 1.3382±0.001, respectively.

Table 4.1.6

Coating solution	Refractive index
AG	1.3360±0.005
AG.11	1.3368±0.002
AG.22	1.3376±0.001
AG.33	1.3382±0.001

As illustrated in the graph, the base formulation (AG), composed of pectin (1.75 g), gum Arabic (0.25 g), and aloe vera gel (0.5 g), exhibited an RI of 1.3360±0.005. With the addition of CMC at increasing concentrations, the RI values rose progressively, with AG.11, AG.22, and AG.33 displaying RI values of 1.3368±0.002, 1.3376±0.001, and 1.3382±0.001, respectively. This consistent rise in refractive index with increasing CMC concentration suggests enhanced molecular interactions and solute dispersion within the solution. The increase in RI is indicative of higher solute content and improved structural integrity of the formulation. Such changes reflect the formation of a denser polymer network due to intermolecular hydrogen bonding and polymer chain entanglements among pectin, gum Arabic, aloe vera gel, and CMC.

4.1.7 Zeta Potential:

The zeta potential values of the base formulation (AG) and its CMC-enriched variants (AG.11, AG.22, and AG.33) are tabulated in Table 4.1.7

Table 4.1.7

Coating solution	Zeta Potential
AG	-20.1mv
AG.11	-19.8 mv
AG.22	-24.2mv
AG.33	-22.0 mv

The base formulation (AG), composed of pectin, gum Arabic, and aloe vera gel, exhibited a zeta potential of approximately –20.1 mV, indicating a moderately stable system with sufficient electrostatic repulsion among particles to prevent aggregation. Upon incorporation of increasing concentrations of carboxymethyl cellulose (CMC), the zeta potential values shifted more negatively. Specifically, AG.11 showed a zeta potential of around -19.8 mV, AG.22 further decreased to approximately –24.2 mV, while AG.33 exhibited a value close to –22 mV. The most negative zeta potential observed in AG.22 suggests it had the highest stability among all formulations, potentially due to optimal interaction between CMC and the other biopolymers. Interestingly, AG.33 exhibited a slightly less negative value than AG.22, which may indicate the onset of polymer saturation or increased viscosity limiting electrostatic mobility. Overall, the zeta potential results confirm that all formulations exhibit sufficient electrostatic stabilization, with CMC addition enhancing the stability of the colloidal system.

4.1.8 Total Phenolic Content:

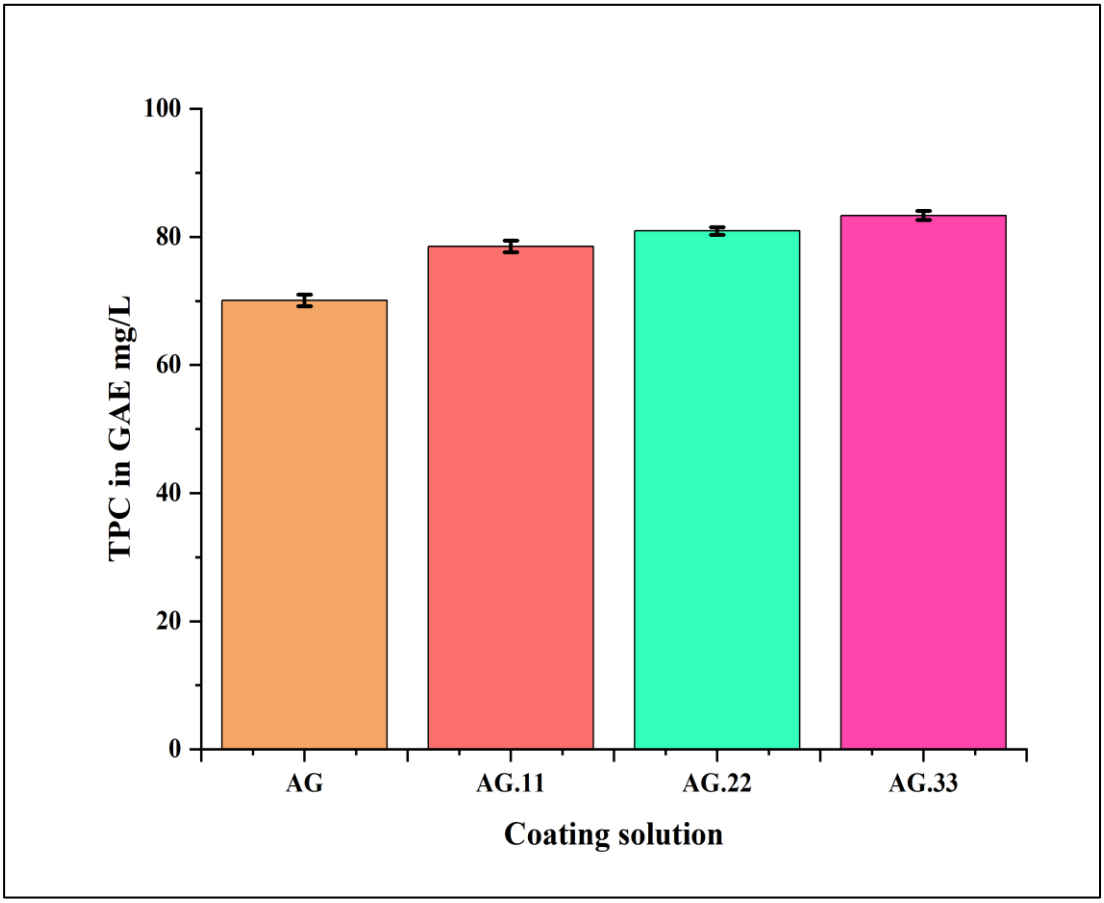

Fig 4.1.8 : TPC of the edible coating with the increase in concentration of CMC

The TPC of edible coating solutions AG, AG.11, AG.22, and AG.33 was quantified and is depicted in Figure. The base formulation (AG), comprising pectin, gum Arabic, and aloe vera gel, exhibited a TPC of 70.10 mg GAE/L (Gallic Acid Equivalents per liter). Upon addition of carboxymethyl cellulose (CMC), a notable increase in phenolic content was observed. Formulations AG.11, AG.22, and AG.33 demonstrated TPC values of 78.53 mg GAE/L, 80.94 mg GAE/L, and 83.35 mg GAE/L, respectively. This incremental rise in TPC with increasing CMC concentration suggests it enhances the extractability or solubility of phenolic constituents, particularly from aloe vera. Additionally, the improved matrix structure due to CMC may reduce phenolic degradation, preserving their antioxidant activity during processing.

4.1.9 Total Antioxidant Capacity:

The ABTS assay is a reliable method to evaluate the free radical scavenging capacity of formulations, reflecting their functional bioactivity. The percentage inhibition values for different formulations—AG, AG.11, AG.22, and AG.33—are presented in Figure 4.1.9.

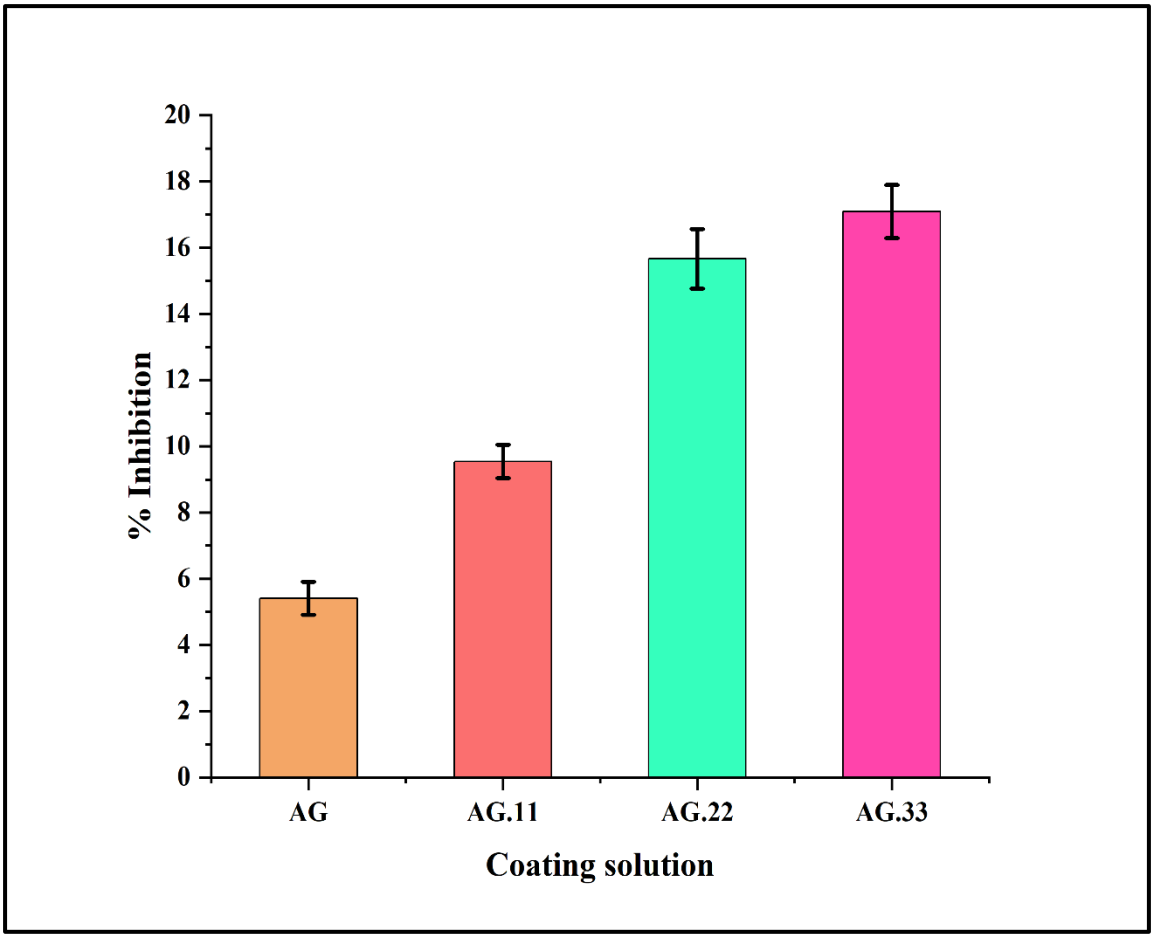

Fig 4.1.9: Antioxidant capacity of the edible coating with the increase in concentration of CMC

The base formulation (AG) exhibited a relatively low % inhibition of 5.41%, indicating limited antioxidant capacity in the absence of additional carboxymethyl cellulose (CMC). However, the inclusion of CMC significantly enhanced the radical scavenging activity. AG.11 showed a marked increase to 9.54%, while AG.22 and AG.33 exhibited even higher values of 15.67% and 17.09%, respectively. This enhancement can be attributed to CMC's ability to improve the structural integrity of the coating matrix, which likely stabilizes and preserves bioactive compounds, especially phenolics, from aloe vera and gum Arabic. These bioactives are known contributors to radical neutralization. In summary, the increasing ABTS% %inhibition with rising CMC concentrations underscores the functional advantage of CMC-enriched coatings.

4.2 Physico-Chemical Properties of Tomatoes

4.2.1 Weight loss:

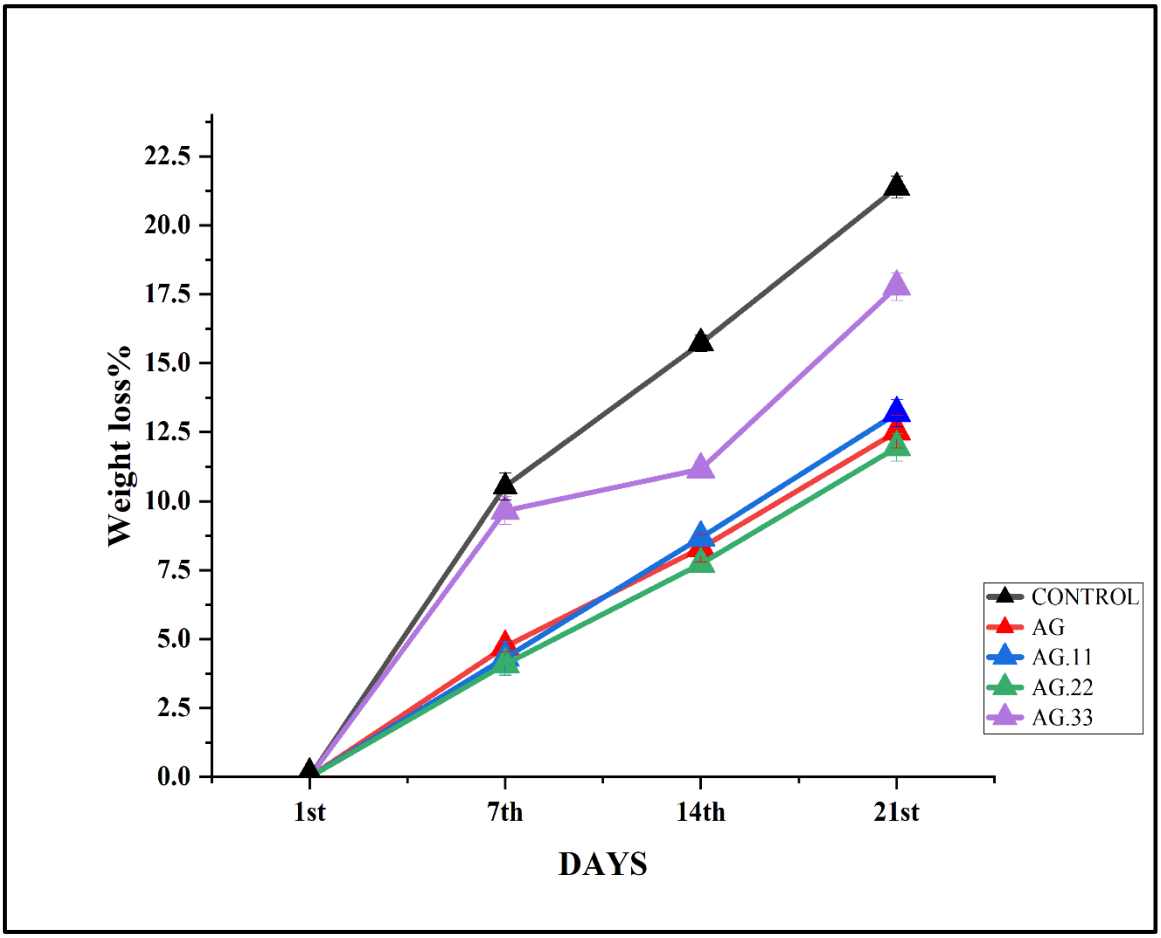

Fig.4.2.1 Weight loss% % in Tomatoes during 21 days of storage

The principal drawbacks in tomato fruit are rapid weight loss during storage, which ultimately leads to a decrease in storage life. Weight loss also indicates the freshness of

fruits. Weight loss increased during storage in all samples as expected. The weight loss of coated and uncoated (control) tomatoes was monitored over a 21-day storage period, and the results are illustrated in Figure 4.2.1.

However, the control tomatoes exhibited the highest percentage of weight loss throughout the storage days, reaching approximately 21.38% by Day 21. This substantial loss is attributable to unrestricted water vapor transmission and high transpiration and respiration rates, which are common in unprotected fresh produce. In contrast, all tomatoes coated with edible coating formulations AG, AG.11, AG.22, and AG.33 showed a significantly reduced rate of weight loss, indicating the effectiveness of the edible coating as a moisture barrier. Among the coated tomato samples, the lowest percentage weight loss was observed for AG.22(11.93%). Furthermore, in comparison to control and coated samples, upsurge in loss of weight was reported highest in AG.33 and lowest in AG.22 samples. The better performance of the AG.22 is due to an optimal concentration balance, providing sufficient barrier properties, good film-forming ability, and better adhesion to the tomato surface without the drawbacks associated with excessive viscosity or rigidity. [27]The moderate levels of CMC incorporation strike a better balance between film integrity, flexibility, and adhesion, all of which are critical for minimizing water vapor transmission and reducing physiological weight loss in tomatoes during storage.

4.2.2 Decay %:

The decay percentage is a critical parameter reflecting tomatoes' postharvest quality and microbial stability during storage. As Figure X illustrates, a substantial decay percentage increase was observed in the control group (uncoated tomatoes), reaching nearly 41.66% by Day 21.

In stark contrast, tomatoes treated with edible coatings demonstrated a progressive decrease in decay, depending on the specific formulation used. Best coating among all was AG.22, as it maintained the quality till the 21st day of the storage study, the decay percentage was 8% only, it outperformed both lower (AG.11) and higher (AG.33) concentration coatings.[10,27]

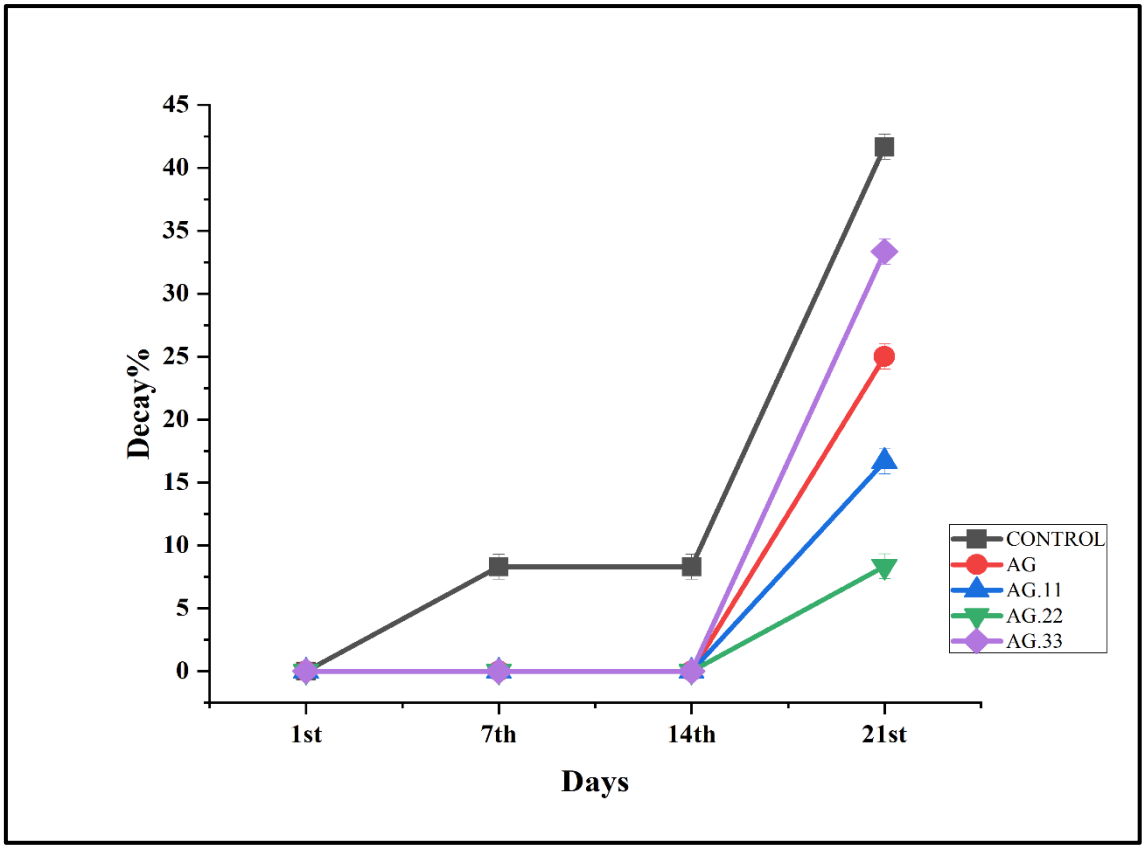

Fig.4.2.2 Decay% in Tomatoes during 21 days of storage

Its superior performance can be attributed to the optimal concentration of CMC (0.22g), which enabled the formation of a uniform and flexible film with effective barrier properties against moisture loss and microbial invasion. Furthermore, AG.22 displayed higher antioxidant capacity, as supported by TPC and ABTS data, contributing to delayed senescence and microbial resistance.[27]

4.2.3 pH:

The pH value, a crucial control parameter, measures acidity and significantly influences the taste and flavour of fruits, making it essential for assessing the shelf-life quality of tomatoes. It also reflects the maturity of the fruit.

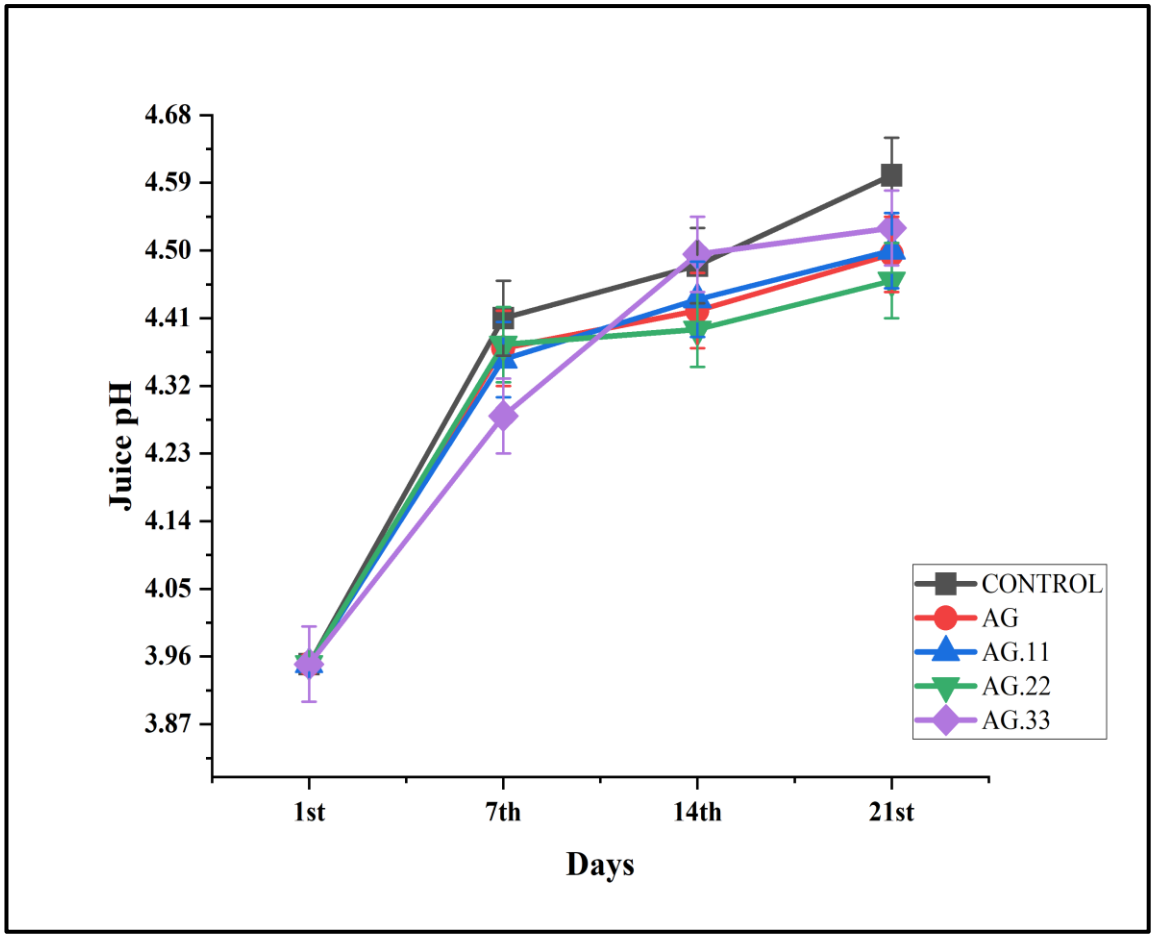

Fig.4.2.3 pH in Tomato juice during 21 days of storage

During storage, it was noted that the pH levels of both coated and non-coated fruits rose. The initial pH of all the samples was 3.95, indicating consistent pH, which increased during the 21 days of storage life, as expected due to the breakdown of organic acids during ripening and microbial activity. The control group showed the most pronounced rise in pH by day 21, reaching values of 4.65, suggesting accelerated breakdown of the organic acid into its salts. All the coating formulations effectively maintained the pH of the juice during the storage days of 21, but among them, particularly AG.22 maintained relatively lower pH levels throughout storage, indicating slower degradation of organic acids and better preservation of fruit quality[12].

4.2.4 %Titratable acidity(%TA):

Titrable acidity is the measure of the content of acid present in a solution, and this parameter is known to be indicative of fruit maturity. Initially (Day 1st), all treatments,

including the control and coated groups, exhibited nearly identical titratable acidity values, around 0.0819%, which is expected as all tomatoes were in a similar fresh state.

During storage days, a general decreasing trend in titratable acidity is observed, which aligns with the expected biochemical changes during ripening, specifically, the metabolic breakdown of organic acids like citric and malic acid. However, the rate of decline varied significantly across treatments. The control group showed the most rapid and pronounced drop in acidity, reaching its lowest point by Day 21, indicative of advanced ripening and senescence. The best coating combination among all was AG.33 as the percentage decrease in titrable acidity was reported to be lowest in this coating combination. AG.33 coatings attained a titrable acidity content of 0.053% as compared to the control sample (0.042%), in which there is a greater loss of acidity of tomato[27]. This suggests that AG.33 was effective in delaying acid metabolism, likely due to its superior film-forming and barrier properties. These coatings reduce oxygen permeability and transpiration, slowing down enzymatic reactions and microbial activity responsible for acid loss.

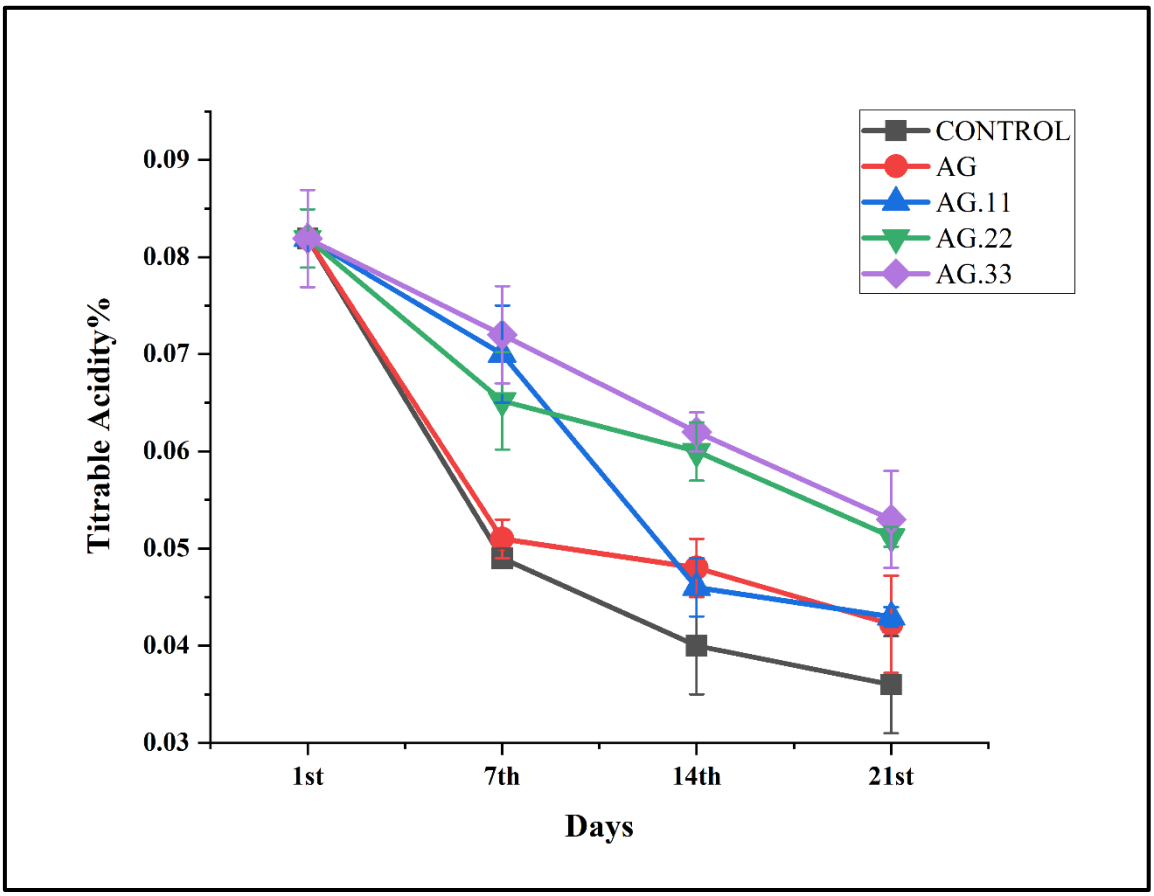

Fig.4.2.4 TA %in Tomatoes during 21 days of storage

4.2.5 Total Soluble Solids (TSS):

Overall, there was a gradual increase in total soluble solids in both coated and non-coated tomato samples. Notably, the non-coated fruits exhibited higher TSS levels, which is typically associated with advanced fruit maturity. The graph represents the changes in total soluble solids (TSS) of tomatoes under different coating treatments over a 21-day storage period. TSS, measured in °Brix, is an indicator of sugar accumulation. As seen in the graph,

all treatments show a general upward trend in TSS, which aligns with the expected physiological changes. However, the extent of increase varies among treatments. The control group shows a modest rise in TSS, indicating standard ripening. In contrast, AG.22 exhibits the steepest and most consistent increase, reaching the highest TSS value by Day 21, suggesting a more advanced sugar development and favourable ripening kinetics. Among all, AG.11 and AG.22 stand out as the most effective coatings, as they promote an optimal and steady increase in TSS, enhancing flavour while likely maintaining structural integrity—ideal traits for postharvest quality retention.[27]

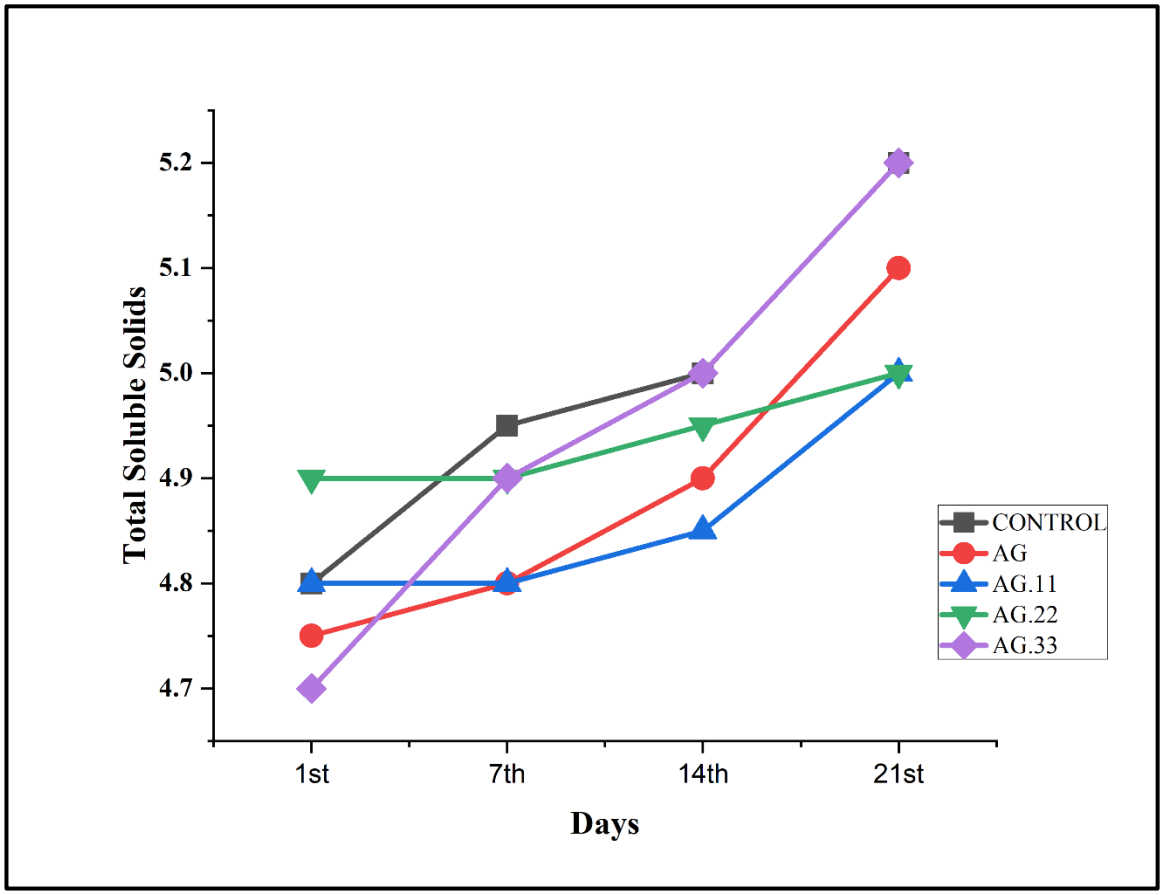

Fig.4.2.5 Total soluble solids in Tomatoes during 21 days of storage

4.2.6 Ascorbic Acid(mg/100g):

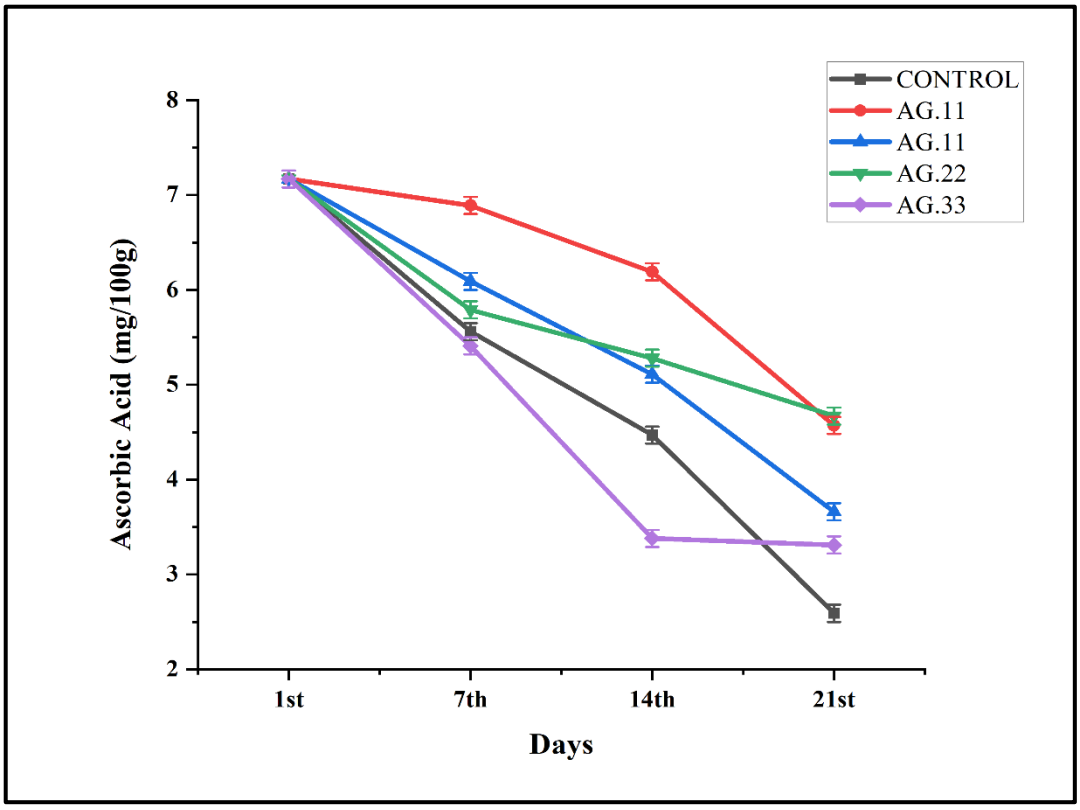

Fig.4.2.6 Ascorbic acid content in Tomatoes during 21 days of storage

Ascorbic acid oxidase is the major enzyme responsible for the oxidation of ascorbic acid in fruits, as a result, the reduction of ascorbic acid content takes place. The graph illustrates the changes in ascorbic acid content in tomatoes over 21 days across different coating treatments and a control. As expected, ascorbic acid levels declined progressively during storage due to oxidative degradation, a natural phenomenon in ripening and senescent fruits. Among all treatments, the coating AG.22 consistently retained the highest ascorbic acid levels (4.67mg/100g) throughout the storage period. This suggests that this particular coating effectively reduced oxidative loss and preserved nutritional quality. In contrast, the control (2.59mg/100g) group and other coatings showed a more rapid decline, indicating lower protective efficacy. During respiration of fruits, ascorbic acid comes in direct contact with oxygen, and autoxidation occurs, which is responsible for the reduction in ascorbic acid content during ripening. Thus, edible coatings seem to have been effective to retard the ascorbic acid degradation, at least until some point of storage life. This was owing to the formation of a covering layer of coating and decreased ease of oxygen to the tomato skin[27]. Thus, AG.22 coating appears to be the most effective in preserving ascorbic acid content during storage.

4.2.7 Lycopene(mg/100g):

Lycopene is a powerful natural antioxidant and the red pigment found predominantly in tomatoes and other red fruits. in uncoated control samples and as well as coated tomatoes with different coating formulations. It also serves as an important indicator of ripeness and postharvest changes during storage. The graph shows lycopene accumulation over 21 days. As tomatoes ripen, lycopene content naturally increases due to the conversion of chlorophyll into carotenoids. The uncoated shows a sharp increase in lycopene from day 7 to 21, reaching the highest levels(12.58mg/100g). While this indicates ripening, it also suggests faster senescence, meaning the fruit is aging rapidly. Tomatoes coated with AG.11 exhibit low lycopene (6.16mg/100g) at day 21, which suggests slow ripening control and good lycopene retention. Other Coatings AG, AG.22, AG.33 show higher lycopene levels, as compared to AG.11, among them AG shows the highest level of lycopene, indicating fast ripening.

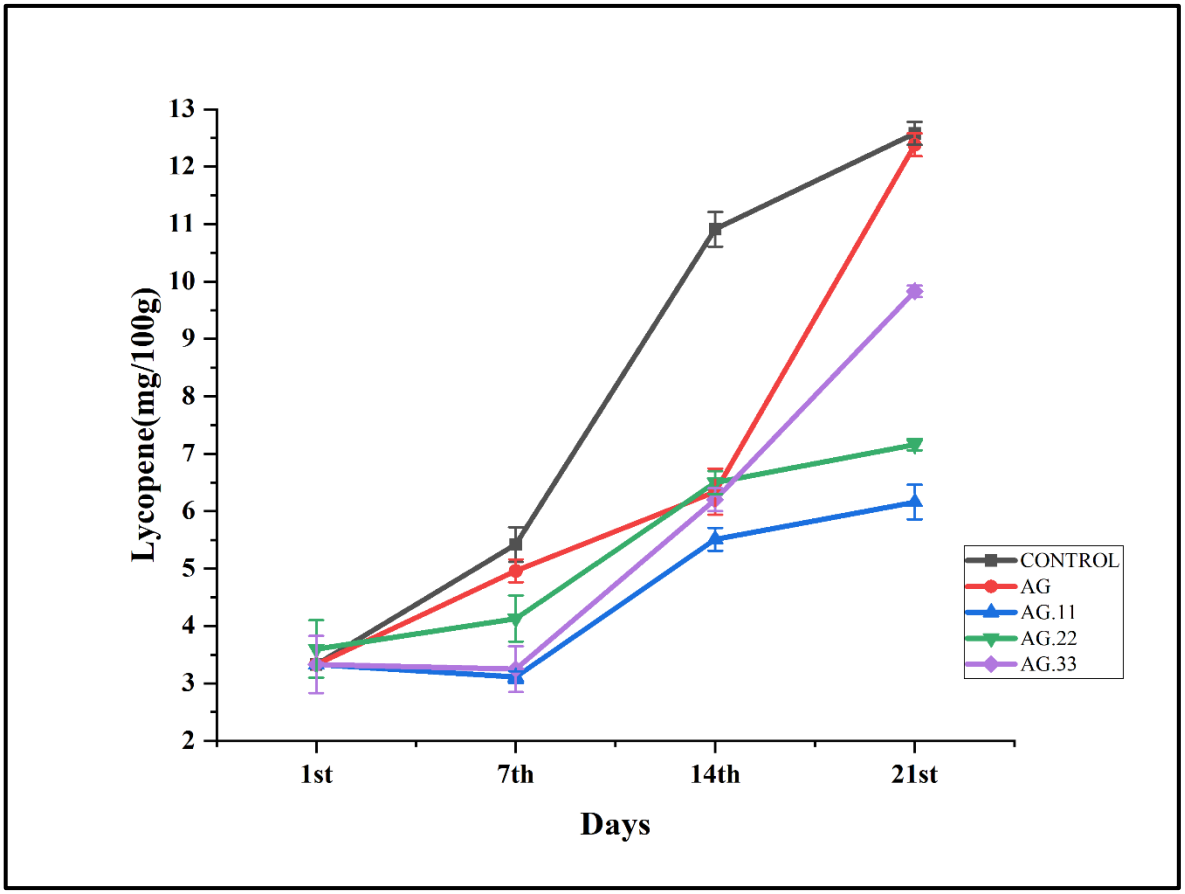

Fig.4.2.7 Lycopene content in Tomatoes during 21 days of storage

4.2.8 Colour:

Table 4.2.8(a): L* values

	CONTROL	AG	AG.11	AG.22	AG.33
DAY 1	30.55±0.1	35.11±0.2	35.23±0.2	38.68±0.1	35.56±0.5
DAY 7th	29.63±0.5	34.21±0.5	33.53±0.3	36.65±0.4	31.78±0.2
Day 14th	29.01±0.2	29.33±0.1	31.23±0.5	35.23±0.5	29.251±0.4
Day 21st	28.533±0.6	29.006±0.6	30.19±0.8	31.39±0.1	29.63±0.2

The L* value reflects the lightness of tomato skin, indicating surface brightness and freshness. Over 21 days, all samples showed a decline in L*, suggesting ripening and darkening. However, tomatoes coated with AG.22 maintained the highest L* values, indicating better colour retention and delayed spoilage. In contrast, uncoated (control) tomatoes showed the lowest lightness, confirming faster deterioration. These results highlight AG.22 as the most effective coating for preserving visual quality during storage.

Table 4.2.8(b): b* values

	CONTROL	AG	AG.11	AG.22	AG.33
DAY 1	30.75±0.2	27.463±0.5	23.2±0.3	14.43±0.2	25.11±0.1
DAY 7th	35.49±0.5	30.69±0.4	30.56±0.2	26.96±0.5	28.745±0.5
Day 14th	37.13±0.6	37.11±0.7	37.73±0.5	32.95±0.2	35.56±0.4
Day 21st	38.59±0.2	39.75±0.2	39.58±0.1	31.39±0.7	34.7846±0.2

The b* value represents the yellowness component in the colour profile of tomatoes, often associated with ripeness and visual appeal. Across 21 days, all treatments showed a decline in b* values, indicating progressive ripening and pigment degradation. However, tomatoes coated with AG.22 consistently retained higher b* values, demonstrating better preservation of colour intensity compared to uncoated samples, which showed a sharp decrease. This suggests that the AG.22 formulation effectively slowed down enzymatic browning and maintained a better overall appearance during storage.

Table 4.2.8(c): a* values

	CONTROL	AG	AG.11	AG.22	AG.33
DAY 1	30.28±0.2	32.006±0.6	28.96±0.6	40.43±0.2	34.78±0.6
DAY 7th	26.5±0.5	27.56±0.5	25.7±0.2	35±0.5	24.49±0.5
Day 14th	16.8±0.6	20.993±0.2	22.24±0.3	31.69±0.4	20.66±0.7
Day 21st	11.63±0.8	16.8±0.5	20.56±0.4	25.69±0.2	15.63±0.2

The a* value reflects the redness intensity of tomatoes, a key indicator of ripening and consumer appeal. As shown in the graph, all samples displayed a general upward trend in a* values over the 21-day period, confirming ongoing ripening. Control and AG-coated tomatoes reached peak redness by Day 21, while AG.22 exhibited a more controlled and gradual increase. This suggests that the AG.22 coating may have moderated the ripening process, potentially delayed over-ripening and extending shelf life while still maintaining desirable colour development.[10]

4.2.9 Respiration rate:

4.2.9(a) O_2 concentration:

The graph illustrates the oxygen (O_2) concentration, an indirect measure of respiration rate, in packaged tomatoes under different treatments over 14 days. A declining trend in O_2 concentration is evident across all treatments, indicating increased respiration over time. The control group shows the steepest decline, reaching the lowest O_2 level by day 14, suggesting the highest respiration rate. In contrast, the AG treatment maintains a relatively higher O_2 concentration, implying a slower respiration rate. Among the AG variants, AG.22 is most effective in moderating respiration, followed closely by AG.11 and AG.33. This reduction in respiration may be attributed to the modified atmosphere created by AG treatments, which potentially slows down metabolic activity and delays senescence. Consequently, AG treatments, especially AG.22, appear to enhance the postharvest shelf life of tomatoes by mitigating O_2 depletion and thus respiration.[27]

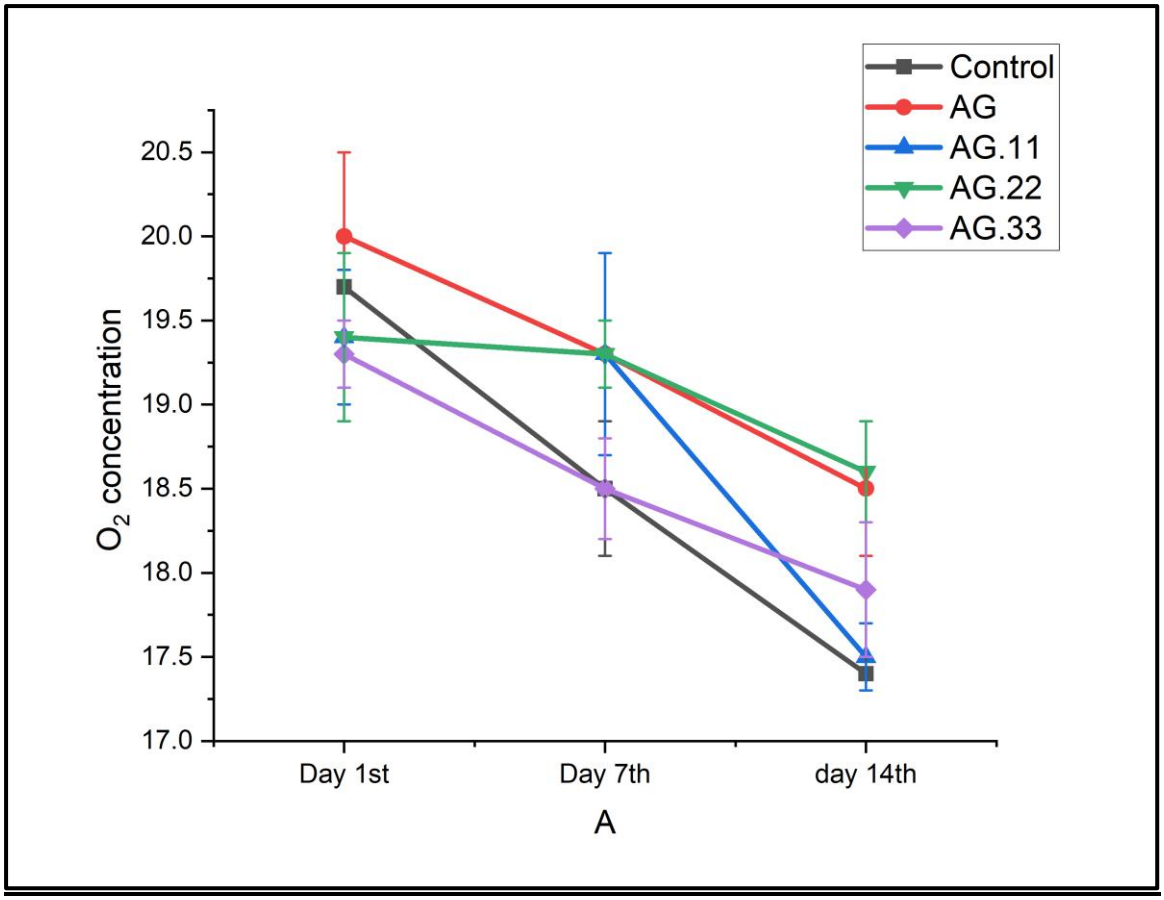

Fig.4.2.7(a) O2 concentration in Tomatoes during 21 says of storage

4.2.9(b) CO_2 Concentration:

The graph shows the carbon dioxide (CO_2) concentration in packaged tomatoes under different treatments over 14 days, serving as a direct indicator of respiration activity. A progressive increase in CO_2 levels is observed across all groups, consistent with ongoing metabolic respiration. The control group exhibits the highest CO_2 accumulation by day 14, signifying elevated respiration and faster deterioration. In contrast, the coated tomatoes, particularly AG.22, show significantly lower CO_2 buildup, indicating suppressed respiratory activity.[27] This trend suggests that edible coating treatment create a more favourable microenvironment by limiting oxygen availability and ethylene action, thereby slowing metabolic processes. As a result, AG.22 most effectively retards respiration, enhancing shelf life and postharvest quality in tomatoes.

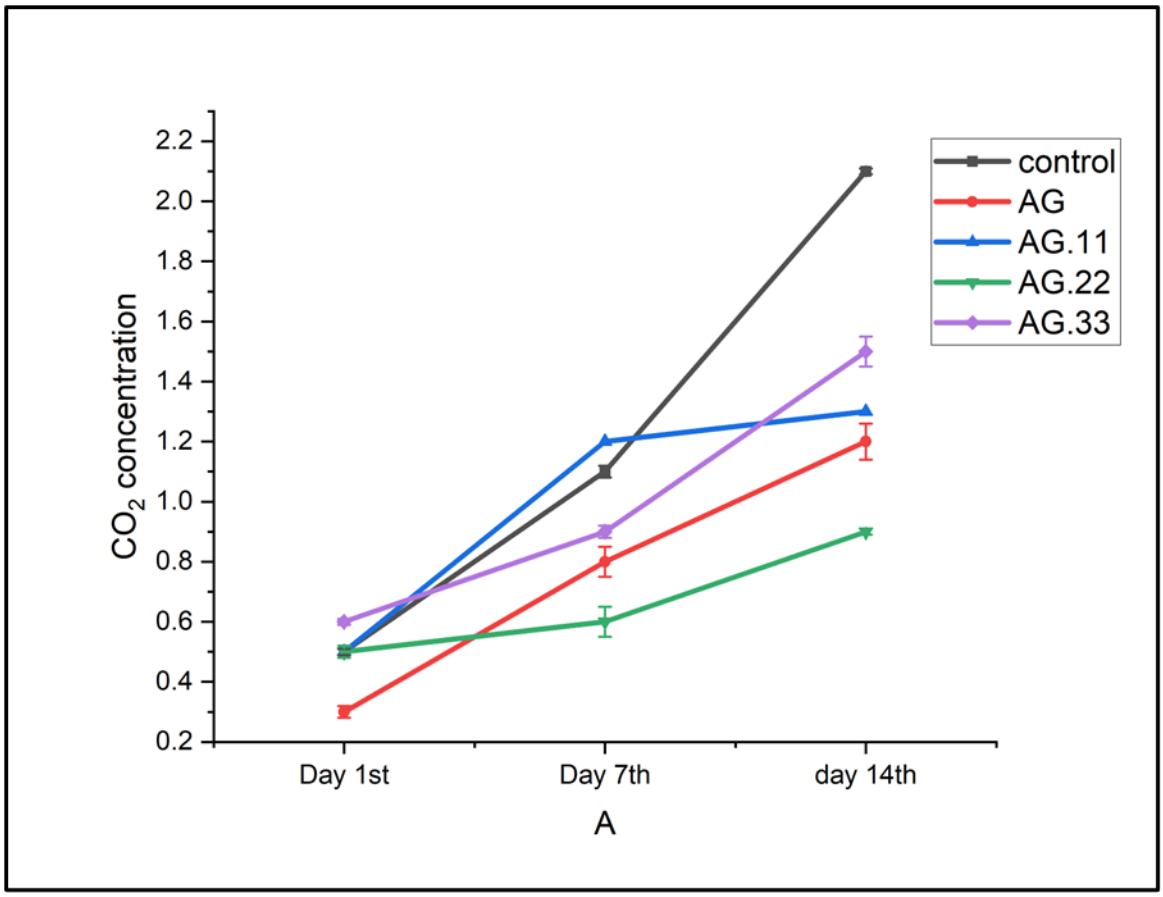

Fig.4.2.7(b) CO2 concentration in Tomatoes during 21 days of storage

4.2Sensory Evaluations:

Sensory evaluation was conducted specifically for the AG.22 edible coating, as it showed the most promising results among all the tested formulations. To assess its consumer acceptability, both coated and uncoated tomatoes were randomly distributed among nearby people. The participants were unaware of which samples were coated and which were not (blind test). They were then asked to complete a feedback form, evaluating various sensory parameters using a 9-point hedonic scale, where 1 indicated “dislike extremely” and 9 indicated “like extremely”.

- The radar chart for Day 1 shows that coated tomatoes consistently scored higher across all sensory attributes—appearance, texture, colour, odour, taste, juiciness, and cutting ability—compared to uncoated ones. This indicates that the coating helped maintain the initial quality, likely by reducing moisture loss and delaying oxidative and microbial changes. These effects are known to preserve textural

integrity, colour vibrancy, and freshness, resulting in better overall sensory perception right from the start of storage.

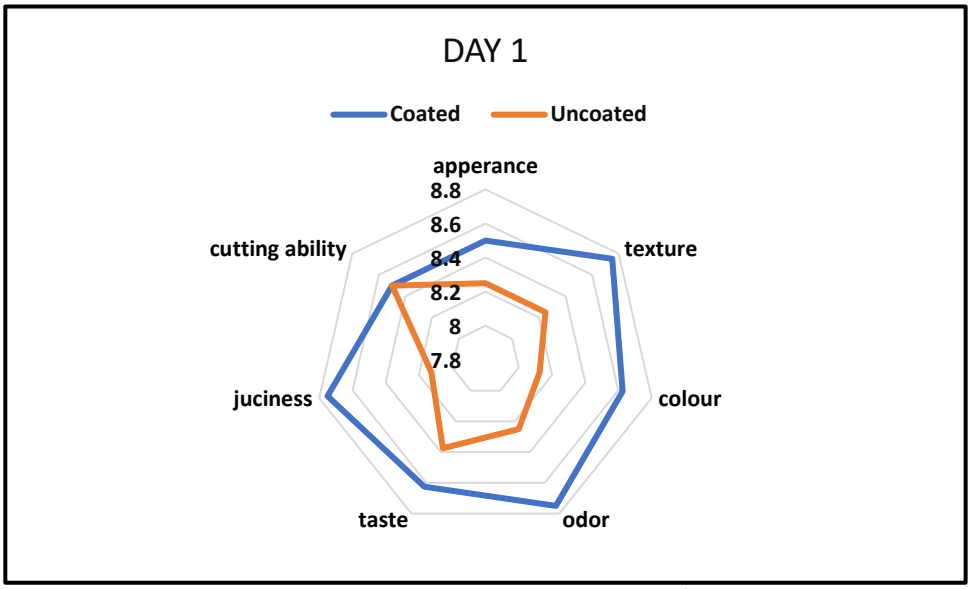

Fig.4.3(a)Sensory evaluation of Tomatoes on 1st day of storage

- On Day 7, coated tomatoes maintained noticeably higher scores in all sensory parameters—appearance, texture, colour, odour, taste, juiciness, and cutting ability—compared to uncoated samples. This suggests that the coating effectively slowed down physiological degradation and moisture loss, which are common in fresh produce during storage. The barrier properties of the coating likely reduced respiration rate and microbial activity, helping preserve freshness and overall quality for a longer duration.

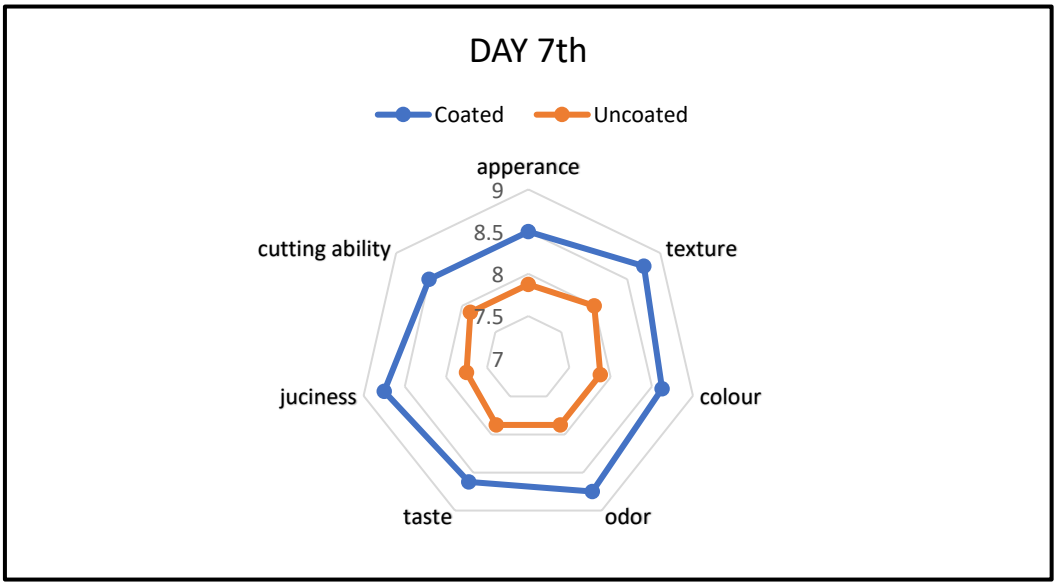

Fig.4.3(b)Sensory evaluation of Tomatoes on 7th day of storage

- The radar chart presents the sensory evaluation of coated and uncoated tomatoes on the 14th day across seven attributes: appearance, texture, colour, odor, taste, juiciness, and cutting ability. Coated tomatoes consistently scored higher in all parameters, with values around 7.5 to 8, indicating better preservation of sensory qualities. In contrast, uncoated tomatoes scored lower (around 6.5 to 7), suggesting a decline in quality. This implies that coating helps maintain the sensory characteristics of tomatoes more effectively over time.

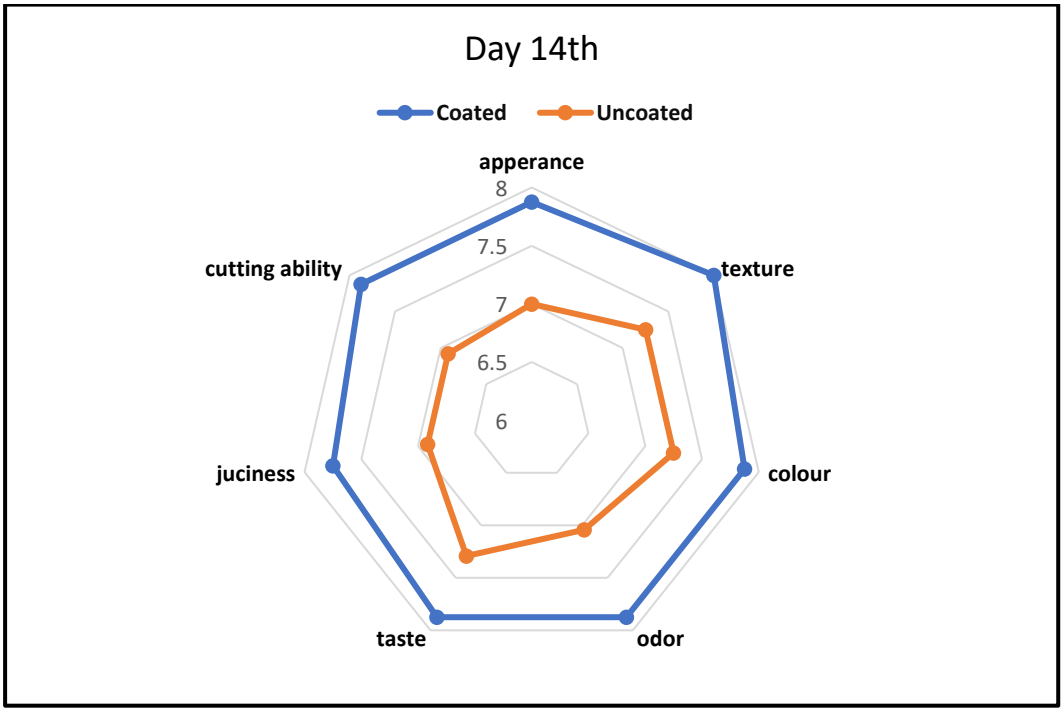

Fig.4.3(c) Sensory evaluation of Tomatoes on 14th day of storage

	1st Day	21th Day
Control		
AG		
AG.11		
AG.22		
AG.33		

Fig. 4.4 Images of the Tomatoes under study during a storage period of 21 days

CHAPTER 5

CONCLUSION

The findings of this study demonstrate that the synergistic application of edible coatings composed of pectin, gum Arabic, aloe vera gel, and carboxymethyl cellulose (CMC) offers a highly effective strategy for extending the shelf life and preserving the postharvest quality of tomatoes stored for 21 days at ambient conditions (24–27°C, 53–58% relative humidity). Tomatoes treated with these coatings experienced significantly reduced degradation of key nutritional components such as ascorbic acid, total phenolics, flavonoids, and also exhibited more stable pH and titratable acidity levels compared to untreated samples. Additionally, the coated tomatoes showed marked delays in weight loss and decay progression, both critical indicators of freshness and marketability.

Among the various formulations tested, the AG.22 coating emerged as the most effective. It notably minimized weight loss and decay percentage while helping to maintain optimal oxygen levels within the packaging environment throughout storage. This formulation also excelled in retaining important bioactive compounds, including ascorbic acid and lycopene, better than the other coating variants. The superior performance of AG.22 is attributed to the inclusion of 0.22 g CMC per 100 mL solution of the base mixture—pectin, gum Arabic, and aloe vera gel in a ratio of 1.75:0.25:0.5 (w/v). The comparison of sensory evaluations clearly shows that tomatoes coated with AG.22 maintained higher rankings across all parameters—appearance, texture, taste, juiciness, and more—throughout the 14 days compared to uncoated tomatoes. While uncoated samples showed a significant decline in quality by day 14, coated tomatoes retained their freshness, flavour, and overall acceptability. This demonstrates that AG.22 coating effectively preserves sensory attributes and extends the shelf life of tomatoes. This precise combination not only enhanced the functional properties of the coating but also proved to be environmentally friendly and practical for postharvest application.

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